ISSN 1742-1705 Volume 24 Number 2 June 2009

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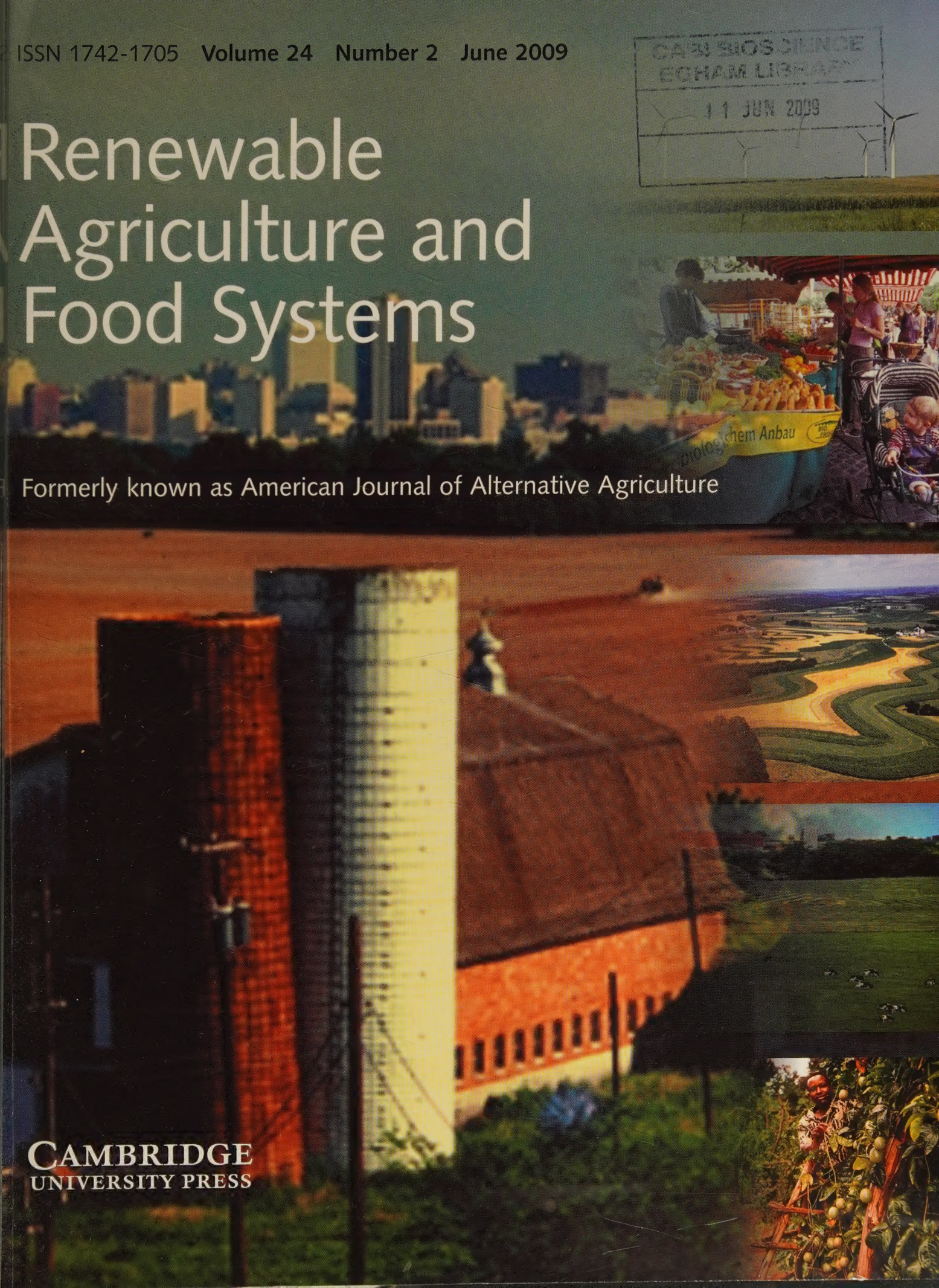
Formerly known as American Journal of Alternative Agriculture



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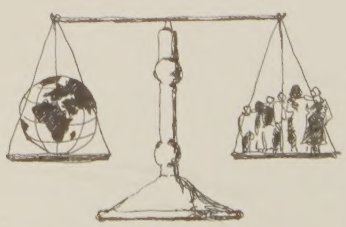

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Renewable Agriculture and Food Systems: 24(2); 85–91 doi:10.1017/S1742170508002470

Organic broccoli production on transition soils: Comparing cover crops, tillage and sidedress N

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Accepted 8 November 2008; First published online 26 February 2009 **Preliminary Report**

Abstract

Little information is available about how farmers in transition to organic practices should manage short- and long-term N fertility. The objectives of this research were (1) to evaluate the leguminous cover crops lablab (*Dolichos lablab* L.), soybean (*Glycine max* L.), sunn hemp (*Crotalaria juncea* L.) and a mixture of sunn hemp and cowpea (*Vigna sinensis* Endl.) as N sources; (2) to compare N availability and broccoli yield when cover crops were incorporated with conventional tillage (CT) or retained as a surface mulch using no-tillage (NT) practices; and (3) to quantify the amount of supplemental sidedress nitrogen required to maximize the yield of organic broccoli (*Brassica oleracea* Group Italica) on transition soils. Broccoli was grown during the first year after organic transition in the spring and fall of 2006 at the Kentland Agricultural Research Farm near Blacksburg, VA. Spring ($P < 0.001$) and fall ($P < 0.001$) broccoli yield increased as the rate of sidedress N was increased up to 112 kg N ha^{-1}, and showed a quadratic correlation with leaf N ($P = < 0.001$, $R^2 = 0.80$ and $P = < 0.001$, $R^2 = 0.38$, respectively). There was no difference in spring broccoli yield between CT and NT; however, CT produced the highest yield in the fall crop. At low sidedress N rates, leaf N was highest in CT plots, but tillage had no effect on N uptake at high N rates. This indicates that early season and perhaps total plant-available mineralized N was greater in CT than NT; however, potential N deficiency in NT soil may be compensated by sidedress N. Broccoli yield was not affected by leguminous cover crop, even though the quantity of cover crop biomass and N contribution was different among species. This suggests that N availability from leguminous cover crops may be impacted by other ecological processes such as soil microbial activity. This study shows that organic CT and NT growers can maximize broccoli yield in transition soils low in N availability, by using leguminous cover crops in combination with moderate amounts of sidedress N.

Key words: *Brassica olercea* Group Italica, sustainable agriculture

Introduction

During transition from conventional to organic farming, yields can be limited by nitrogen (N) availability[1–4]. In comparison with synthetic fertilizers, organic N, from cover crops or other sources, is slowly broken down by microbial activity[5,6]. As a result, synchronizing crop N demand with microbial N release is a serious challenge for organic growers[3,7]. Little information is available about how farmers in transition to organic practices should manage short- and long-term N fertility[8].

Short-term N availability is essential for maximum productivity. Tillage increases available N for plants[9]. Soil microbial populations are stimulated and immobilized N within soil organic matter is made available to plants after tillage[9–11]. Furthermore, low carbon-to-nitrogen organic residues, such as leguminous cover crops, supply varying amounts of organic N depending on cover crop biomass and quality[12,13]. Finally, timely applications of precision-placed supplemental N enhance fertilizer use efficiency, which improves yield and reduces N leaching[8].

Beyond transition, organic systems depend on long-term N-use efficiency to balance productivity with sustainability[5]. Reduced tillage improves soil aggregation, which augments the capacity of the soil to act as a N reservoir[14]. High carbon-to-nitrogen cover crops such as grasses promote soil development with high organic inputs, scavenge and redistribute residual N above ground, and reduce N loss

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Table 1. Cover and vegetable crop sequences, 2003–2006.

	Cropping sequences	
Season/year	**Spring**	**Fall**
Fall 03–spring 04	Winter cover crop mixture—rye (*Secale cereale* L.) and hairy vetch (*Vicia villosa* Roth)	Winter cover crop mixture—rye and hairy vetch
Spring–summer 04	Irish potato (*Solanum tuberosum* L.)	Summer squash (*Cucurbita maxima* Duchesne)
Fall 04–spring 05	Winter cover crop mixture—barley (*Hordeum vulgare* L.) and crimson clover (*Trifolium incarnatum* L.)	Winter cover crop mixture—barley and crimson clover
Spring–summer 05	Summer cover crops—LL and SH	Sweet pepper (*Capsicum frutescens* L.), overseeded with annual ryegrass[1]
Spring–summer 06	Spring broccoli	Summer cover crops—LL, SH and SH/CP
Summer–fall 06		Fall broccoli

[1] On 29 July 2005, annual ryegrass (*Lolium multiflorum* Lam.) was overseeded in established pepper plots. After final pepper harvest in late September, ryegrass grew well and completely covered all plots during fall 05–spring 06.
CP, cowpea; LL, lablab; SH, sunn hemp.

through the soil profile[7]. As a result, management strategies that integrate cover crop rotations and attempt to reduce tillage may result in more sustainable and productive organic systems.

The objectives of this study were to quantify the amount of supplemental N required to maximize organic broccoli yield, to evaluate the ability of various leguminous cover crops to supply N, and to compare the effect on N availability and broccoli yield when cover crops were incorporated with conventional tillage (CT) or retained as a surface mulch using no-tillage (NT) practice.

Materials and Methods

Experiments were conducted in the spring and fall of 2006 at the Virginia Tech, Kentland Agricultural Research Farm, near Blacksburg, VA, on a Hayter loam soil (fine-loamy mixed, mesic Ultic Hapludaf, pH 6.4 at 4–6 cm soil depth). The field plots were in their first year after a 3-year organic transition period; conventional field corn in 2002 was followed by applying aged chicken manure in 2003 ($3\,t\,ha^{-1}$) and growing combinations of cover crops and vegetable crops in 2003–2005 (Table 1).

The experimental design was a randomized split split-block. Spring treatments were cover crops as main plots (3.7 m × 130 m), tillage system as subplots (3.7 m × 65 m) and nitrogen (N) rate as sub-subplots (3.7 m × 16.3 m), with two replications. Fall treatments were arranged differently, with tillage system as main plots (3.7 m × 130 m), cover crop as subplots (7.4 m × 43.3 m) and sidedress N rate as sub-subplots (7.4 m × 7.6 m), with four replications. For both crops, tillage systems were CT, in which the cover crops were flail mowed and incorporated 15-cm deep using a tractor-drawn rotary tiller, and NT, in which the cover crops were flailed mowed and the residues left on the surface as organic mulch. Two weeks after transplanting, subplots received four rates of organic N fertilizer (Tables 2 and 3). Total N was calculated per plot based on the treatment rate and applied uniformly by hand.

Table 2. Calendar of events.

Operation	**Spring**	**Fall**
Sow cover crops	25 Jul[1]	15 Jun
Seed broccoli in greenhouse	17 Mar	10 Jul
Sample cover crop and weed biomass	19 Apr	14 Aug
Roll (spring) or flail-mow (fall) cover crop	10 Nov[1]	15 Aug
Incorporate cover crop residues in CT plots	20 Apr	15 Aug
Transplant broccoli seedlings	25 Apr	17 Aug
Apply base fertilizer	25 Apr	17 Aug
Critical hand weeding	26 Apr	8 Sep
Fertilize through drip irrigation	3 May	24 Aug
Apply sidedress N	9 May	7 Sep
Sample broccoli leaves for tissue N analysis	12 Jun	3 Oct
Apply Bt for pest control	–	11 Oct
Harvest first crop	13 Jun	1 Nov
Harvest second crop	22 Jun	10 Nov
Harvest third crop	–	14 Nov

[1] Signifies operation in 2005.
Bt, *Bacillus thuringiensis*.

All plots consisted of either two or four 15-cm-high raised beds on 183 cm centers, and with cover crops, zone-seeded using a 10-row (18.3 cm apart) Tye drill (Agco Corporation, Duluth, GA). In both experiments, legume species were seeded on bed tops (73 cm wide) where broccoli transplants would be later set (grow zones) and grass species were seeded in alleyways (55 cm wide) on both sides of the grow-zone, which included bed edges, sides and bottoms. Cover crop seed was separated inside the hopper, so proper seed was drilled into its respective location.

For the spring crop, lablab (LL) and sunn hemp (SH) were seeded in grow zones and sorghum sudangrass (SSG) in alleyways. For the fall crop, LL, soybean (SB) and an SH

Table 3. Delivery method, time of application, and sources of organic N fertilizer spring and fall, 2006.

Delivery method and time of N application	N regime ($kg\,N\,ha^{-1}$)			
N fertilizer source	**A**	**B**	**C**	**D**
In-row base application at transplanting				
Harmony organic 5N–2.2P–2.5K	45	45	45	45
Fertigation at 1 week				
Soluble organic fertilizer[1]	5	5	5	5
Hand-sidedressed N at 2 weeks				
Sodium nitrate (16%)	0	22	34	45
Feathermeal (12%)	0	34	88	123
Total sidedress N	0	56	112	168

[1] Sodium nitrate ($3.5\,kg\,N\,ha^{-1}$) and fish and seaweed extract mix ($1.5\,kg\,N\,ha^{-1}$).

and cowpea (CP) mixture (SH–CP) were seeded in grow zones and pearl millet (PM) in alleyways. Seeding rates were 45, 40, 56, 45, 90 and 15–75 $kg\,ha^{-1}$ equivalent for SSG, PM, LL, SH, SB and SH–CP, respectively. Each row of the Tye drill was regulated separately to ensure a desirable seeding depth and subsequent uniform stand over the surface of the entire bed.

An early maturing broccoli cultivar (Major) was planted in spring, and a mid-season cultivar (Gypsy) planted in fall (Seedway Seed Co., Elizabethtown, PA). Broccoli transplants were produced at the Virginia Tech Horticulture Greenhouse for 6 weeks in 72-cell trays (55 cc/cell) containing an organic potting mix (McEnroe Lite, Millerton, NY). The plants were transported to the farm and acclimated in the shade with daily watering for 10 days before transplanting.

Prior to transplanting, aboveground cover crop biomass samples (0.25 m) were hand cut at the soil surface, dried at 70°C for 14 days, weighed, ground with a cyclone mill and analyzed for total N content using the Kjeldahl procedure[15]. Broccoli transplants were set in twin rows on raised beds (50-cm apart and 37 cm in row) with minimal disturbance of surface mulch or soil, using the Subsurface Tiller–Transplanter (SST–T)[16]. Harmony organic fertilizer (5N–2.2P–2.5K—Harmony Products, Inc., Harrisonburg, VA) and drip tubing (T-Tape-Rainflo Irrigation, LLC East Earl, PA) were applied at planting alongside each row using the SST–T. The same sources and rates of organic fertilizers were applied to both spring and fall broccoli crops (Table 3). All plots were drip irrigated as needed to supplement rainfall shortages. To ensure an adequate stand establishment, any wilted or dead plants were replaced up to 1 week after transplanting. A single fully expanded broccoli leaf was sampled from eight to ten plants per plot during early heading to compare N accumulation. Leaves were combined, dried and analyzed for N as described above.

Weeds were controlled in both crops by swallow cultivation approximately 5–10 days before canopy closure of the twin broccoli rows. Weeding methods included hand pulling and hoeing by hand or push plow. Cover crop mulch in NT plots suppressed weed growth, resulting in fewer weeds and biomass than in CT (data not shown). In the spring, a Multivator (Mitchell Equipment, Marysville, OH) cultivated alleyways between beds in both NT and CT plots 1 week after transplanting.

Insect pests and diseases were kept low by applying recommended nutrients and irrigation to maximize plant health and vigor, planting beneficial insectary strips adjacent to the broccoli rows, and applying a single application of Dipel (*Bacillus thuringiensis*, Valent Corporation, Walnut Creek, CA) at $1.12\,kg\,ha^{-1}$ 3 weeks before the first harvest (Table 2).

Differences in cultivars and growing conditions between spring and fall production seasons affected the maturity rate of broccoli. The harvest began 7 weeks after planting in the spring and 11 weeks in the fall and continued for 10 and 14 days, respectively. Bead tightness and uniformity were the primary selection criteria for harvest. Broccoli heads were cut to a uniform length of 20 cm and checked for hollow stem, counted and weighed for total yield, and sorted into marketable and cull yield. Culls included damaged heads or heads < 8 cm in diameter.

Data were analyzed by ANOVA using SAS (SAS Institute Inc., Cary, NC). Correlation coefficients were calculated using PROC REG with yield as the dependent variable and leaf N as the independent variable. Figures were constructed using CoPlot (CoHort Software, Monterey, CA). Significant statistical differences between treatment means and interactions were determined by LSD at $P < 0.050$.

Results and Discussion

Supplemental N effects

Higher rates of sidedress N fertilizer significantly increased yield in both experiments (Table 4). However, the N requirement for broccoli was fulfilled at $112\,kg\,ha^{-1}$ and there was no significant difference between 112 and $168\,kg\,ha^{-1}$. Higher N rates statistically decreased cull yield, and total yield correlated with average head weight (data not presented). Applied N increased broccoli yield in previous studies[17,18]. Our findings are consistent with Dufault and Waters who reported that increasing the N rate increased

Table 4. Sidedress N effects on broccoli yield, head weight, cull yield, stem hollowness and leaf N in spring and fall, 2006.

N (kg/ha)	Yield (t ha^{-1})	Head wt (g)	Cull[1] (%)	Hollow (%)	Leaf N (%)
Spring					
0	3.9[2] c	197 d	28.1 a	3.9 c	3.21 c
56	5.6 b	272 c	19.6 b	21.4 b	3.95 b
112	6.5 a	307 b	11.5 c	45.4 a	4.58 a
168	6.7 a	330 a	9.9 c	51.3 a	4.82 a
P value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Fall					
0	5.0 c	207 c	13.2 a	50.4 c	3.35 d
56	5.9 b	247 b	9.9 ab	71.5 b	4.59 c
112	6.4 ab	268 a	7.1 b	87.1 a	5.52 b
168	6.7 a	281 a	8.4 b	87.6 a	5.91 a
P value	< 0.001	< 0.001	0.047	< 0.001	< 0.001

[1] All heads < 7.5 cm diameter.
[2] Means within a column followed by different letters are significantly different at the 5% level according to the LSD test.

Table 5. ANOVA summary of treatment interactions for broccoli yield, head weight, cull yield, stem hollowness and leaf N in spring and fall, 2006.

		P value				
Source of variation[1]	df	Yield	Head wt	Cull[2]	Hollow	Leaf N
Spring						
T*CC	1	0.137	*0.015*	0.056	*0.042*	0.667
T*N	3	0.686	0.809	0.771	0.569	0.092
CC*N	3	0.259	0.358	0.248	*0.014*	0.968
T*CC*N	3	0.301	0.101	0.675	*0.036*	0.796
Fall						
T*CC	2	0.076	0.086	0.128	*< 0.001*	0.108
T*N	3	0.619	0.694	0.276	*0.028*	*0.002*
CC*N	6	0.360	0.114	0.354	0.494	0.286
T*CC*N	6	0.122	0.143	0.318	*0.028*	0.920

[1] T, tillage; CC, cover crop; N, nitrogen.
[2] all heads < 7.5 cm diameter.
Values in *italics* are statistically significant (*P* value < 0.050).

broccoli head weight and yield and decreased cull yield[19]. Incidence of hollow stems increased with higher N rates (Table 4). However, effects were variable as indicated by significant cross-treatment interactions of T × CC × N in spring ($P = 0.036$) and fall ($P = 0.028$) (Table 5). Regardless, stem hollowness has been reported to correlate with increased N rate and is considered an indicator of rapid broccoli growth rate[20].

Higher rates of sidedress N increased both yield and percentage of N accumulation in leaf tissue. Optimum leaf N values for broccoli production range from 3.2 to 5.5[21]. For spring, reported leaf N values (Table 4) and the x_{max} value of 5.33 (Fig. 1) fell within the optimum range, while leaf N values for 112 and 168 kg ha^{-1} N (Table 4) and the x_{max} value of 6.31 (Fig. 1) for fall were higher than optimum. Despite different seasonal responses, higher leaf N accumulation resulted in higher yield for both crops. Other studies identified similar relationships among rate of applied N, leaf tissue N accumulation and broccoli yield[22,23]. Kowalenko and Hall showed that higher N fertilization rates significantly increased N in leaves and broccoli heads without stimulating vegetative growth[24]. As a result, broccoli leaf N content can be utilized as an indication of broccoli yield potential.

Tillage effects

Yields of organic spring broccoli were not different between NT and CT, although NT decreased stem hollowness relative to CT (Table 6). These results are consistent with broccoli yield data from other NT studies[25–27]. During the fall experiment, NT yields were lower than that in CT; however, NT still decreased stem hollowness. Mulched cover crops in NT systems are known to reduce soil temperature and slow plant growth compared with CT systems[14]. During vegetative growth, a sudden drop to subzero temperatures for 4 consecutive days in mid-October caused uniform leaf damage and subsequent yield loss in all plots

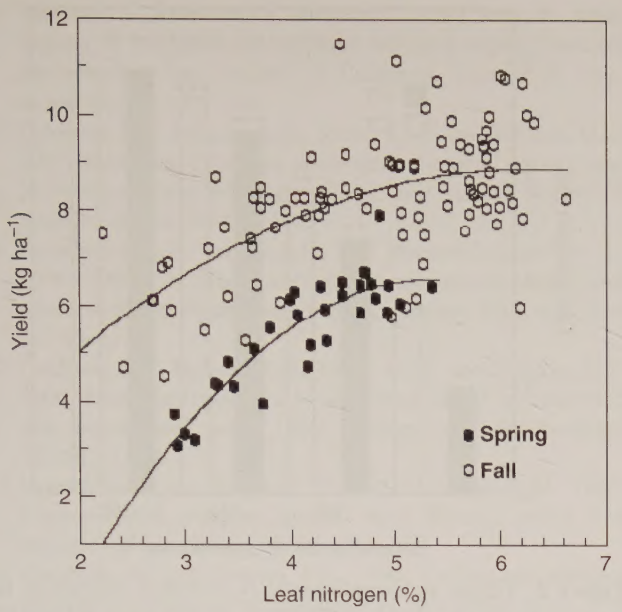

Figure 1. Quadratic correlation between leaf nitrogen and broccoli yield for spring ($P < 0.001$; $y = -9.89 + 6.18x - 0.58x^2$; $R^2 = 0.80$; $x_{max} = 5.33$) and fall ($P < 0.001$; $y = 0.59 + 2.65x - 0.21x^2$; $R^2 = 0.36$; $x_{max} = 6.31$).

(Table 7). Under these conditions, smaller NT plants did not recover to the same extent as larger CT plants; thus, NT yields were affected to the greatest extent.

Tillage affects both seasonal and long-term N availability and thus can play an important role in determining total yield. In this study, a significant tillage × sidedress N interaction ($P = 0.002$) occurred for broccoli leaf N (Fig. 2). Without additional N, availability and corresponding N uptake in NT plots were reduced. Research has shown that using tillage to incorporate plant residues releases earlier and higher rates of N compared with NT mulched soil[10]. Furthermore, as the rate of sidedress N increased, N uptake by NT plants approached levels of CT (Fig. 2). Our study is consistent with past research that showed that supplemental N may be required to increase N availability in NT[28].

Cover crop effects

The quantity and quality of cover crop residues have determined N contribution in past studies[13,29,30]. Cowpea and tall growing SH created an environment where both crops could thrive due to differences in plant architecture, thereby resulting in higher cover crop biomass than the other treatments. In the spring, SH residues were greater than LL and had higher plant N (Table 8). In general, LL and SB had more leafy and succulent residues than SH and SH–CP. The relative proportion of leaves and stems largely determine the quality of cover crop residues, rate of mineralization and release of plant-available N[13].

For both spring and fall, broccoli leaf N and yield were not influenced by cover crop treatment (Table 8). The lack of response could be attributed to the failure of N contained in CC residue to significantly affect available soil-N for the subsequent broccoli crop. This hypothesis is further supported by the lack of CC × N interactions for spring and fall broccoli yield and leaf N, even at lower N regimes of 0 and 56 kg ha^{-1} N (Table 5). Differences in quality of LL and SB may have compensated for greater biomass and N contribution of SH and SH–CP in terms of N mineralization. However, soil analysis was not conducted to confirm this hypothesis.

Conclusion

This study shows that both indigenous soil organic matter and applied fertilizer are required to maximize crop yield in transition soils. Over time, reliance on N fertilizers may decrease as buildup of soil organic matter and biologically buffered N availability are achieved from growing soil-building cover crops, applying organic waste products and a commitment to conservation agriculture[5,31].

In our experiments, all plots were conducted on flat land and used drip irrigation to minimize soil moisture deficits. Therefore, any potential advantages of NT surface mulch in conserving soil moisture and increasing broccoli yield were minimized. Early season N availability and plant growth were greater in CT than in NT systems in our transition soil. Based on this and similar studies[8], when using organic high-biomass NT systems in transition soils, we recommend applying soluble organic fertilizers at planting and through the drip irrigation system (fertigation) to meet early season demands.

Table 6. Tillage effects on broccoli yield, head weight, cull yield, stem hollowness and leaf N in spring and fall, 2006.

Tillage[1]	Yield (t ha^{-1})	Head wt (g)	Cull[2] (%)	Hollow (%)	Leaf N (%)
Spring					
CT	5.7	280	17.1	33.3	4.2
NT	5.7	274	17.4	27.7	4.08
P value	0.948	0.218	0.857	0.024	0.152
Fall					
CT	6.4	266	6.6	80.3	5.02
NT	5.5	236	12.8	68	4.66
P value	< 0.001	< 0.001	< 0.001	0.011	< 0.001

[1] CT, conventional tillage; NT, no tillage.
[2] All heads < 7.5 cm diameter.

Table 7. Minimum temperatures for October 2006 at the Kentland Research Farm. Days 13–16 are in bold type to emphasize the sudden drop to subzero temperature.

Day	Minimum temp. (°C)	Day	Minimum temp. (°C)
1	2.8	17	2.8
2	4.4	18	6.6
3	5.6	19	8.9
4	6.6	20	10.0
5	8.3	21	−0.6
6	11.1	22	0.0
7	5.6	23	1.1
8	6.6	24	−1.7
9	7.2	25	−1.1
10	5.6	26	−3.8
11	4.4	27	−2.2
12	10.0	28	5.0
13	**−4.4**	29	4.4
14	**−5.0**	30	−0.6
15	**−5.0**	31	0.0
16	**−3.4**		

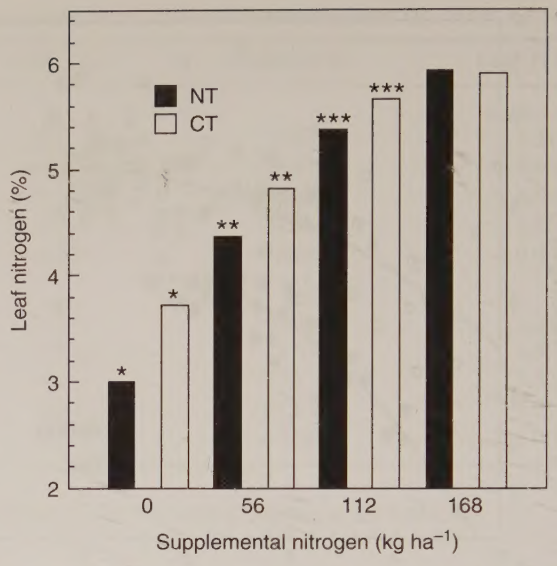

Figure 2. Tillage and supplemental N treatment interaction for broccoli leaf N ($P = 0.002$) fall 2006; *, **, *** mean NT and CT values significantly different at $P < 0.05$, 0.01 or 0.001, respectively.

Table 8. Cover crop species, biomass, plant N percentage, and cover crop N contribution and their effects on broccoli leaf N and yield in spring and fall, 2006.

Cover crop				Broccoli	
Species[1]	Biomass (t ha^{-1})	Plant N (%)	N[2] (kg ha^{-1})	Leaf N (%)	Yield (t ha^{-1})
Spring					
LL	2.0 b*	0.75 b	15 b	4.18	5.6
SH	3.5 a	0.92 a	32 a	4.10	5.8
P value	0.005	0.011	0.002	0.285	0.445
Fall					
LL	4.6 b	2.35	110 b	4.86	6.1
SB	5.2 b	2.17	112 b	4.69	5.8
SH-CP	7.0 a	2.19	153 a	4.97	6.1
P value	0.004	0.225	0.007	0.215	0.445

[1] LL, lablab; SH, sunn hemp; SB, soybean; SH–CP, sunn hemp and cowpea mix.
[2] Cover crop N contribution calculated as aboveground × plant N (%).
* Means within a column followed by different letters are significantly different at the 5% level according to the LSD test.

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Renewable Agriculture and Food System: 24(2); 92–101 doi:10.1017/S1742170508002445

Effect of different cover crops on organic tomato production

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Accepted 1 October 2008; First published online 26 February 2009 **Research Paper**

Abstract

When animal husbandry is not included in organic farming systems, green manure may be crucial to preserve or increase soil organic matter content and to ensure an adequate N supply to crops. Different species, both legumes and nonlegumes, may be used as cover crops. The present research was carried out to investigate the effect of different green manure crops [oats and barley mixture (*Avena sativa* L. and *Hordeum vulgare* L.), rye (*Secale cereale* L.), brown mustard (*Brassica juncea* L.), flax (*Linum usitatissimum* L.), pigeon bean (*Vicia faba* L. var. *minor*)] on the production of the following tomato crop. A field trial was conducted for two cropping seasons (2003–2004 and 2004–2005) in a commercial organic farm. The yield of tomato crop was positively affected by pigeon bean, although statistically significant differences in comparison with the other treatments were observed only in 2004–2005, when the experiment was conducted in a less fertile soil. This was probably due mainly to the effect of the pigeon bean cover crop on N availability. In fact, this species, in spite of a lower biomass production than the other cover crops considered in the study, provided the highest N supply and a more evident increase of soil N-NO_3. Also, cover crop efficiency, evaluated using the N recovery index, reached higher values in pigeon bean, especially in the second year. The quality of tomato fruits was little influenced by the preceding cover crops. Nevertheless, when tomato followed pigeon bean, fruits showed a lower firmness compared to other cover crops, and in the second year this was associated with a higher fruit N content.

Key words: organic farming, tomato, cover crops, nitrogen

Introduction

Italian production of organic vegetables covers an area of 17,000 ha[1]. Tomato is one of the most widespread crops, grown on 2013 ha, including both fresh market tomato and processed tomato, with a mean yield of about 55 tons per hectare[1]. In vegetable crop rotations, tomato is generally the most profitable crop.

In organic farming, any strategy to preserve soil fertility is particularly important. When animal husbandry is not included in the farming system, green manure is crucial to preserve or increase soil organic matter content and to ensure an adequate N availability to crops.

The amount of N supplied to the soil by cover crops is due to both the degradation of cover crop biomass and, in case of leguminous species, symbiotic N fixation. Since this amount is strongly affected by different factors, such as soil conditions and lignification level of crop residues, variable data may be found in the literature[2–4]. The management of cover crop biomass (destroyed and turned under or mowed and left on soil surface as a mulch) also plays an important role in determining the rate of N released into the soil and available for the following cash crops. In comparison with mulching, turning under generally decreases the exposure of biomass to air and atmospheric agents, while enhancing contact with microbial biomass. This would not only produce an initial slower mineralization of cover crop residues, but also a subsequent faster degradation of most lignified and carbon-rich tissues. Turning under may nevertheless improve soil organic matter mineralization, often also reducing soil moisture and the content of organic C and N in the first 20 cm depth[5,6].

Among leguminous winter cover crops, pigeon bean, pea and common vetch, incorporated into the soil at the full

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flowering stage, have been reported to supply the highest amounts of N[7]. About 30–50% of this N is released in the first season after green manure, while the rest is released over the following 2 years[8]. The peak of nitrate-N availability in the soil is normally detected in the first 2 months after green manure. For this reason, a tomato crop preceded by a leguminous cover crop can reach the same yield as that obtained when N fertilizers are used[9,10]. On the other hand, in very fertile soils green manure may have poor beneficial effects.

The highest yields of marketable tomato fruits are obtained with N doses of 150–200 kg ha^{-1} and a fertilizer efficiency between 0.59 and 0.71[11]. It is possible to achieve amounts of total N between 229 and 295 kg ha^{-1} when pigeon bean is used as the green manure crop, depending on when it is turned under[7]. Cover crops can also be used in addition to organic N fertilizers in tomato crop, allowing a reduction of their amounts to even one-half[12,13]. Furthermore, Piazza et al.[14] and Kumar et al.[15] observed a positive interaction between green manure and the addition of N by compost or mineral fertilizer distribution.

Species other than legumes may also be used as cover crops, e.g. belonging to *Graminaceae* and *Brassicaceae*, especially when an allelopathic effect[16–18] and a biocide action are required in addition to the supply of N and organic matter in the soil.

The present research was carried out to investigate the effect of different green manure crops on the production of the tomato crop that followed. In particular, to verify whether an eventual effect could be especially related to N made available for the tomato crop, the influence of the different cover crop species on N dynamics in the soil was studied in detail.

Materials and Methods

The research was carried out during the 2003–2004 and 2004–2005 growing seasons at the Bonamici Organic Farm, located in San Martino Ulmiano, Pisa, Italy (lat. 43°46′, long. 10°24′). Five cover crops [oats and barley mixture (*Avena sativa* L. and *Hordeum vulgare* L.), rye (*Secale cereale* L.), brown mustard (*Brassica juncea* L.), flax (*Linum usitatissimum* L.) and pigeon bean (*Vicia faba* L. var. *minor*)] plus a weedy no-cover crop control were compared and their effect on the following crop (tomato) was evaluated. Soil characteristics of the experimental fields used for the 2003–2004 trial and 2004–2005 trial, respectively, are reported in Table 1.

Table 1. Soil characterization of the trial fields (0–30 cm soil depth).

	2003–2004	2004–2005
pH	6.89	7.40
Organic matter (g kg^{-1})	25.30	26.60
Total N[1] (g N kg^{-1})	1.56	1.28
Assimilatable P[2] (mg P_2O_5 kg^{-1})	41.68	28.76
Exchangeable K (mg K_2O kg^{-1})	273.61	Not determined
Electrical conductivity (dS m^{-1})	0.22	0.08
Sand (%)	56.57	43.59
Silt (%)	38.28	44.23
Clay (%)	5.15	12.18

[1] Kjeldahl method.
[2] Olsen method.

In both years, the experimental design was a randomized complete block with two replications (1 replication = 1 plot). Plot size was 250 and 70 m^2, respectively, in 2003–2004 and 2004–2005. Details on cover crop varieties, 1000-seed weight and seed rate are reported in Table 2.

In the two trials, cover crops were sown on October 7, 2003 and on November 19, 2004, respectively. Before and after the sowing, the soil was harrowed by a tine harrow. Neither irrigation water nor fertilizers were applied to the cover crops. Cover crops were cut up by a mulcher for stalks (April 23, 2004; May 9, 2005) and turned under by a disk harrow after 2 days. Before cutting, aboveground cover crop biomass production was estimated over three and over two sampling areas of 1 m^2 in each plot in 2004 and 2005, respectively. Samples were oven-dried at 75°C until constant weight and biomass was expressed on a dry matter basis. Samples were then analyzed for total N concentration (Kjeldahl method). Only for 2005 samples, organic C concentration (Walkley and Black method) was also determined and C/N ratio calculated.

Tomato (*Lycopersicon esculentum* Mill.) cv. *Palinuro*, an F1 hybrid with cylindrical fruits suitable for both the fresh market and the processing industry, was transplanted on May 28, 2004 and on May 17, 2005 with a 1.30 × 0.35 m spacing on a soil mulched by a biodegradable Mater-bi® film. A perforated hose was placed under the mulching for

Table 2. Cover crop varieties, 1000-seed weight and seed rate.

Species	Common name	Variety in 2003–2004	Variety in 2004–2005	1000-seed weight (g)	Seed rate (kg ha^{-1})
A. sativa L. + *H. vulgare* L.	Oats + barley	Argentina + Prosa	Argentina + Orchidea	34.5 + 45.6	100 + 50
S. cereale L.	Rye	Fasto	Fasto	65.5	150
B. juncea L.	Brown mustard	ISCI 61	ISCI 61	2.8	12
L. usitatissimum L.	Flax	Barbara	Barbara	7.5	70
V. faba L. var. *minor*	Pigeon bean	Vesuvio	Vesuvio	249.5	200

Table 3. Root dry biomass and root N content considered for the calculation of N recovery.

Species	Root dry biomass (% of total dry biomass)	Root N content ($g\,kg^{-1}$)
Oats + barley	10.5[1]	15.7[2]
Rye	16.3[24]	5.0[25]
Brown mustard	9.6[26]	20.0[27]
Flax	5.7[28]	10.2[28]
Pigeon bean	4.8[21]	15.0[21]
Tomato	9.1[29]	26.3[29]

[1] Mean value between oats[21] and barley[22].
[2] Mean value between oats[21] and barley[23].

drip irrigation. Weed control was performed by hand weeding. In order to protect the plants against cryptogamic diseases, copper sulfate was sprayed periodically during high atmospheric humidity condition. Tomato yield from four plants located in two sampling areas per plot was assessed at harvest time (on August 31, 2004 and on August 30, 2005). Fruits collected from the sampled plants were counted, weighed and sorted into three classes: marketable fruits (ripe fruits), green and turning fruits and discardable fruits. On two ripe fruits per plant, the following parameters were determined: fresh weight, dry weight (by oven-drying at 75°C until constant weight), firmness (measured by a penetrometer), juice soluble sugar concentration expressed as Brix values (measured with a refractometer) and, only for fruits harvested in 2005, juice acidity (measured by a pH meter). Crop residues (stems and leaves) of the sampling areas were also weighed and then oven-dried at 75°C until constant weight, in order to determine the biomass production on a dry matter basis. Finally, samples of ripe fruit and cultural residue dry biomass were analyzed for total N concentration (Kjeldahl method).

Recovery by tomato crop of N supplied by the different cover crops was calculated, according to Wagger[19] and Schroeder et al.[20], both as the difference ($kg\,ha^{-1}$) between N removed by tomato crop following a cover crop and N removed by control tomato crop, and as percent ratio between this difference and N supplied by the cover crops. In order to better evaluate N recovery, the amount of N contained in the cover crop and tomato roots was also included in the calculation. Root dry matter production and root N content, which were not detected in our experiment, were taken from the literature (Table 3).

Soil NO_3^- concentration (ion chromatography; DIONEX) in the top 30 cm of the profile was determined on the following days: September 26, 2003 and April 23, May 26, June 16, July 9, July 28, August 20, September 24, 2004 (2003–2004 trial); November 18, 2004 and May 9, June 11, June 30, July 23, August 13, September 1, September 22, 2005 (2004–2005 trial). Note that on April 23, 2004 and on May 9, 2005 the cover crop cutting took place. Climatic conditions during the period of the trials in 2003–2004 and 2004–2005, respectively, are shown in Figure 1.

For both the trials, experimental data were subjected to analysis of variance (ANOVA) according to a randomized block design with two replicates, and means were compared using the LSD test at $P \leqslant 0.01$ and $P \leqslant 0.05$ level of significance. The arc sine values of all percent data were previously calculated, except for N recovery, the data of which were converted into $\log_{10}(x+30)$ or $\log_{10}[(\%/100)+1]$ depending on whether it was expressed as $kg\,ha^{-1}$ or percent values. For N recovery mean data (averaged over the 2003–2004 and 2004–2005 data), a split plot experimental design was adopted, with year as the main factor and cover crop as the subplot factor.

Results and Discussion

Cover crops

As shown in Table 4, in 2003–2004 cover crops produced considerable amounts of dry matter ($9.77\,t\,ha^{-1}$ on average for the five tested crops). This was ascribed to the excellent fertility of the soil (Table 1) as well as to the climatic conditions (Fig. 1) occurring both at sowing and during the spring, with temperature and rainfall favorable for cover crop growth (temperature falling below 0°C only in the last 10 days of January).

The oats and barley mixture showed the highest biomass production ($11.55\,t\,ha^{-1}$), although no statistically significant differences were detected in comparison with brown mustard and flax (10.37 and $10.16\,t\,ha^{-1}$, respectively); rye and pigeon bean yields were instead significantly lower (8.50 and $8.29\,t\,ha^{-1}$, respectively) (Table 4).

The tested cover crops differed also in biomass N concentration (Table 4): the minimum value was found in flax ($13.88\,g\,kg^{-1}$), while the maximum ($28.45\,g\,kg^{-1}$) was detected in pigeon bean, as expected on account of symbiotic N fixation. Owing to its high N content that compensated for the low biomass production, pigeon bean, although not significantly different from brown mustard and oats and barley mixture, showed a higher N supply than rye and flax (Table 4).

The cover crops showed different C/N ratios compared to those previously reported by Reeves[30], Quemada et al.[31], Uprety and Mahalaxmi[26], Garmash[32], Mazzoncini et al.[33]; pigeon bean and brown mustard showed lower values than flax and cereals (Table 4).

In 2004–2005, cover crop biomass production (Table 4) was drastically lower than that of the previous year (−47% on average). The reasons are likely to be found in the characteristics of the experimental site: lower N and P soil content (Table 1; Figs. 2 and 3) and adverse climatic conditions (Fig. 1). The plentiful rainfall in autumn caused a delay in sowing and consequently in the emergency of cover crops. Besides, temperatures in January, February and March were very low (minimum temperature below 0°C). The delay of sowing not only caused a shortening of the cover crop cycle by almost 1 month in comparison with the previous year, but also exposed seeds to cold temperatures that

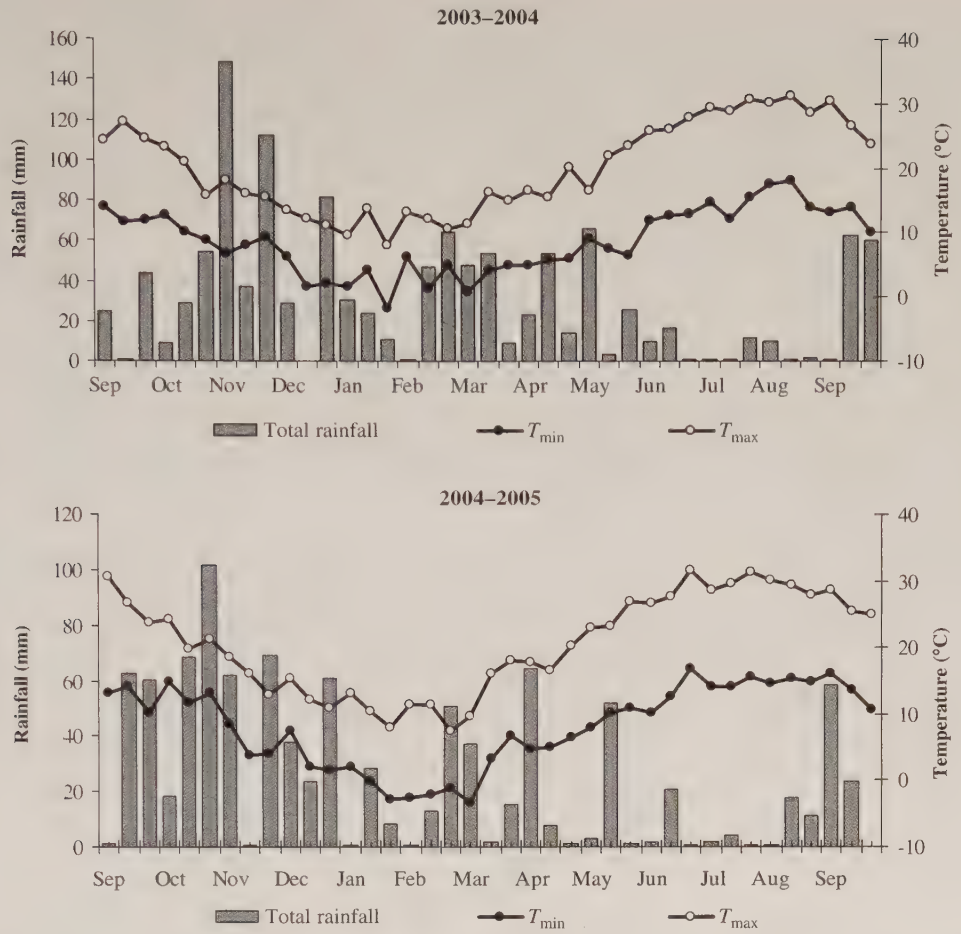

Figure 1. Climatic trend (rainfall and maximum and minimum temperature—values per 10 days) in San Martino Ulmiano (Pisa) during the 2003–2004 (top) and 2004–2005 (bottom) seasons.

Table 4. Cover crop dry biomass and its N content, N supply by cover crops and, only for 2003–2004 trial, cover crop C/N ratio.

	2003–2004				2004–2005		
Species	**Dry biomass ($t\,ha^{-1}$)**	**N content ($g\,kg^{-1}$)**	**N supply ($kg\,ha^{-1}$)**	**C/N ratio**	**Dry biomass ($t\,ha^{-1}$)**	**N content ($g\,kg^{-1}$)**	**N supply ($kg\,ha^{-1}$)**
Oats + barley	11.55a	15.91cd	183.76ab	28	5.82b	9.40cd	54.71b
Rye	8.50b	18.65bc	158.53b	24	7.09a	7.65e	54.24b
Brown mustard	10.37a	21.58bc	223.78a	20	5.34bc	8.05de	42.99b
Flax	10.16a	13.88d	141.02b	30	1.25d	11.50bc	14.38c
Pigeon bean	8.29b	28.45a	235.85a	15	6.40ab	27.05a	173.12a
Significance	**	**	**	ns	**	**	**

In each column, means followed by the same letter are not significantly different at $P \leqslant 0.05$ (*) and $P \leqslant 0.01$ (**) (LSD test).

partly compromised their germination. This was regular only for rye, while it was particularly poor for flax and nonhomogeneous for all the other species. Furthermore, the low temperatures and the poor rainfall occurring in the last phase of cover crop cycle also probably contributed to reduce their growth. Cover crop dry biomass at incorporation time into the soil reflected the situation observed at emergence: rye and pigeon bean were the most productive, while flax yield was the lowest (Table 4).

As observed in 2003–2004, pigeon bean N content ($27.05\,g\,kg^{-1}$) was higher than that of all the other cover crops, and also close to the value observed for the same species in the previous year (Table 4). Considering the average of all cover crops, the amount of N accumulated in the biomass was 35% less than that observed in 2003–2004 (Table 4), probably due to the lower content of readily available N in the soil (Figs. 2 and 3). In such conditions, the incidence of symbiotic N fixation was particularly decisive,

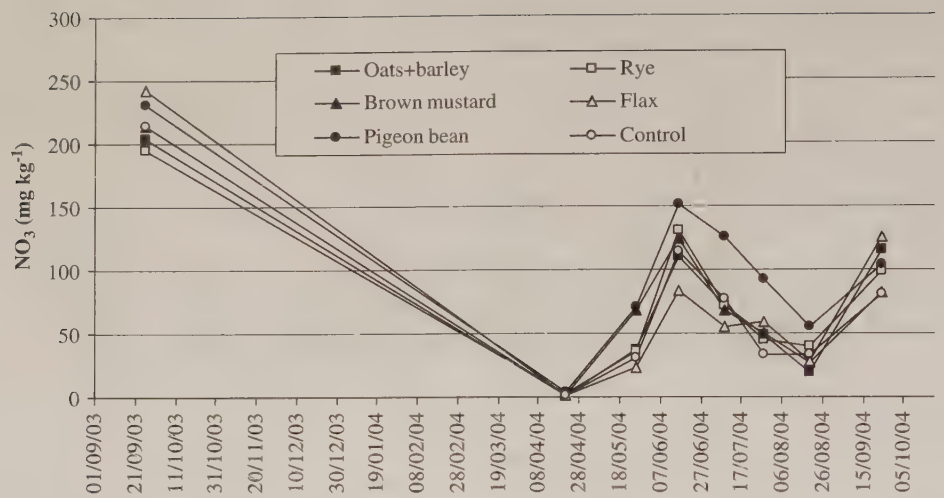

Figure 2. Soil NO_3 in the field used in the 2003–2004 trial.

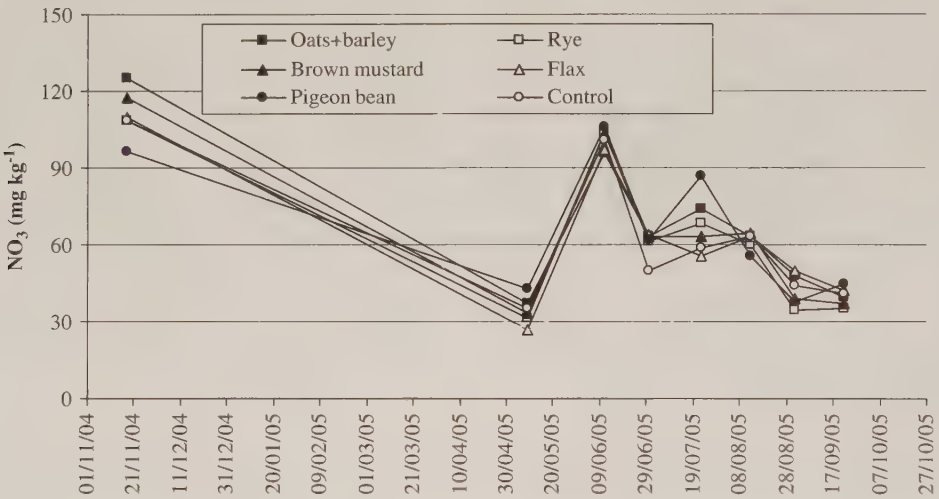

Figure 3. Soil NO_3 in the field used in the 2004–2005 trial.

emphasizing the differences in N accumulation between pigeon bean and the other cover crops (Table 4).

Soil nitrate

In 2003–2004, nitrate in the soil showed a similar trend for all the tested cover crops (Fig. 2). At cover crop sowing (October 7, 2003) soil average nitrate content was 217 mg kg^{-1}. During cover crop growing, due to both plant absorption and leaching, soil nitrate decreased to an average value of 2 mg kg^{-1} soon before cover crops were turned under. A progressive increase of soil nitrate was observed from green manure incorporation into the soil (April 23, 2004) to the middle of June (54 days after), when all the treatments reached the highest level. The decrease that followed till the end of August can be ascribed to tomato crop absorption and to a slow down in the mineralization process, probably correlated with the poor rainfall that occurred in this period. On the contrary, the plentiful rainfall that followed tomato harvesting, together with high temperatures, may have reactivated mineralization, and this could explain the new increase in soil nitrate detected on September 24, 2004. Comparing the different cover crops it can be noticed that, after green manure incorporation into the soil and until tomato harvesting, the highest values of soil nitrate, with statistically significant differences for most of the survey dates, were found in the pigeon bean plots (Fig. 2); therefore, this species was the most effective in releasing mineral N to the soil.

The soil in the 2004–2005 trial was characterized by a lower starting content of nitrate (111 mg kg^{-1} on average at cover crop sowing, on November 19, 2004) and lower levels were reached after cover crops were turned under (Figs. 2 and 3). On the contrary, at the end of cover crop cycle (May 9, 2005) soil nitrate was higher (34 mg kg^{-1} as average value) than the year before (Figs. 2 and 3), as cover crops recovered a smaller amount of soil N due to their lower biomass production (Table 4). As a result of green

Table 5. Fruit yield (number of fruits per m^{-2}) obtained by tomato crop following the compared cover crops.

	2003–2004				2004–2005			
Species	Marketable fruits ($n\,m^{-2}$)	Green and turning fruits ($n\,m^{-2}$)	Discardable fruits ($n\,m^{-2}$)	Total fruits ($n\,m^{-2}$)	Marketable fruits ($n\,m^{-2}$)	Green and turning fruits ($n\,m^{-2}$)	Discardable fruits ($n\,m^{-2}$)	Total fruits ($n\,m^{-2}$)
Oats + barley	64.5	41.2	12.5	118.2	50.6	20.9ab	18.7	90.2b
Rye	71.1	51.0	17.3	139.4	56.0	9.6b	19.0	84.6b
Brown mustard	61.6	35.8	15.9	113.2	52.1	6.6b	30.8	89.5b
Flax	71.5	36.2	13.2	120.9	57.1	11.3b	18.1	86.5b
Pigeon bean	77.9	44.9	10.3	133.0	71.7	33.0a	21.7	126.4a
Control	61.6	39.6	17.4	118.6	48.3	11.5b	20.7	80.5b
Significance	ns	ns	ns	ns	ns	*	ns	*

In each column, means followed by the same letter are not significantly different at $P \leqslant 0.05$ (*) and $P \leqslant 0.01$ (**) (LSD test).

Table 6. Fruit yield obtained by tomato crop following the compared cover crops.

	2003–2004				2004–2005			
Species	Marketable fruits ($kg\,m^{-2}$)	Green and turning fruits ($kg\,m^{-2}$)	Discardable fruits ($kg\,m^{-2}$)	Total fruits ($kg\,m^{-2}$)	Marketable fruits ($kg\,m^{-2}$)	Green and turning fruits ($kg\,m^{-2}$)	Discardable fruits ($kg\,m^{-2}$)	Total fruits ($kg\,m^{-2}$)
Oats + barley	5.6	3.1ab	1.1a	9.8	4.8b	0.8	1.5	7.1ab
Rye	5.4	2.4bc	0.9a	8.8	4.5b	0.3	1.3	6.1b
Brown mustard	5.0	3.7a	0.8ab	9.5	4.2b	0.3	1.8	6.3b
Flax	6.1	2.9ab	0.6bc	9.6	4.6b	0.4	1.4	6.4b
Pigeon bean	6.2	1.9c	0.4c	8.5	6.1a	0.8	1.7	8.6a
Control	5.0	2.5bc	0.8ab	8.4	3.5b	0.9	1.4	5.8b
Significance	ns	*	**	ns	**	ns	ns	*

In each column, means followed by the same letter are not significantly different at $P \leqslant 0.05$ (*) and $P \leqslant 0.01$ (**) (LSD test).

manure incorporation into the soil, the nitrate peak was reached after 33 days (Fig. 3). No statistically significant differences in nitrate content were noticed among the treatments due to the different cover crops. Hence, in 2004–2005 the higher N content and N supply shown by pigeon bean (Table 3) did not correspond to a greater availability of soluble N for the crop immediately following green manure. This seems to confirm the findings of Dufault et al.[34] and Sainju et al.[35], which showed how leguminous cover crops, despite their higher N supply to the soil and their capacity to improve N recovery of tomato, were not more effective than other cover crop species or chemical fertilizers in retaining nitrates in the soil profile, mainly due to the high mobility of nitrate ions.

Tomato crop

Yield and N uptake. Climatic conditions in the summer were quite favorable to tomato crop, with high temperatures (maximum temperature between 25 and 32°C) and poor rainfall in both the years (Fig. 1).

Some positive effects of the legume cover crop on tomato yield were noticeable. Tomato crops that followed pigeon bean gave a higher marketable fruit yield in both the years, although with statistically significant differences in comparison with the other treatments only for yield expressed as fruit amount ($kg\,m^{-2}$) in the 2004–2005 growing season; in the same season the green and turning fruit yield (number of fruits m^{-2}) and the total fruit yield (both number m^{-2} and $kg\,m^{-2}$) were also significantly higher, while in 2003–2004 pigeon bean resulted in the lowest amount ($kg\,m^{-2}$) of discardable fruits (Tables 5 and 6). Also tomato dry matter production and N uptake were positively affected by pigeon bean (Tables 7 and 8). In 2004–2005 growing season, the dry biomass of tomato marketable fruits, leaves and stems, and total, were significantly higher when this species was used as the cover crop, although for marketable fruit dry biomass production the difference was not statistically significant with respect to oats and barley mixture and rye (Table 7), while for tomato N uptake a significant superiority of the legume cover crop over all the other species and the control was detected (Table 8).

These results are in agreement with those of Sainju et al.[36], which showed the same ability of leguminous cover crops to sustain tomato yield, biomass production and N uptake as 90 and $180\,kg\,ha^{-1}$ of N fertilizer. Wang et al.[37,38]

Table 7. Dry biomass obtained by tomato crop following the compared cover crops.

Species	2003–2004			2004–2005		
	Marketable fruit dry biomass ($kg\,m^{-2}$)	Leaf and stem dry biomass ($kg\,m^{-2}$)	Total[1] dry biomass ($kg\,m^{-2}$)	Marketable fruit dry biomass ($kg\,m^{-2}$)	Leaf and stem dry biomass ($kg\,m^{-2}$)	Total[1] dry biomass ($kg\,m^{-2}$)
Oats + barley	0.22	0.27	0.49	0.26ab	0.32bc	0.58b
Rye	0.19	0.30	0.49	0.26ab	0.28c	0.54b
Brown mustard	0.18	0.23	0.41	0.25b	0.31bc	0.56b
Flax	0.23	0.26	0.49	0.25b	0.36bc	0.61b
Pigeon bean	0.24	0.21	0.55	0.32a	0.45a	0.77a
Control	0.15	0.26	0.41	0.20b	0.40ab	0.60b
Significance	ns	ns	ns	*	**	*

In each column, means followed by the same letter are not significantly different at $P \leq 0.05$ (*) and $P \leq 0.01$ (**) (LSD test).
[1] Considering only the aerial part.

Table 8. N uptake by tomato crop following the compared cover crops.

Species	2003–2004			2004–2005		
	Marketable fruit N uptake ($kg\,ha^{-1}$)	Leaf and stem N uptake ($kg\,ha^{-1}$)	Total[1] N uptake ($kg\,ha^{-1}$)	Marketable fruit N uptake ($kg\,ha^{-1}$)	Leaf and stem N uptake ($kg\,ha^{-1}$)	Total[1] N uptake ($kg\,ha^{-1}$)
Oats + barley	77.7	49.4	127.1	54.2b	54.3b	108.5b
Rye	67.1	55.2	122.3	47.1b	46.3b	93.4b
Brown mustard	56.2	39.6	95.8	47.0b	54.6b	101.6b
Flax	76.4	49.4	125.8	43.5b	57.8b	101.3b
Pigeon bean	84.7	62.3	147.0	72.2a	85.2a	157.4a
Control	53.4	50.7	104.1	34.3b	62.5b	96.8b
Significance	ns	ns	ns	**	**	**

In each column, means followed by the same letter are not significantly different at $P \leq 0.05$ (*) and $P \leq 0.01$ (**) (LSD test).
[1] Considering only the aerial part.

and Abdul-Baki et al.[39] in different experiments conducted in South Florida with three legume cover crops [sunn hemp (*Crotalaria juncea* L.), cowpea (*Vigna unguiculata* Walp. ssp. *unguiculata*) and velvet bean (*Mucuna deeringiana* (Bort.) Merr.)] and one nonlegume cover crop [sorghum sudangrass (*Sorghum bicolour* × *S. bicolour*)] followed by tomato obtained variable results, but sunn hemp seemed to be the most favourable species.

Recovery by tomato crop of N supplied by the different cover crops, considering the two trials separately, did not show statistically significant differences both when expressed as the difference ($kg\,ha^{-1}$) between N removed by tomato crop following, respectively, a cover crop and the control, and when expressed as percent ratio between this difference and N supplied by the cover crop (Table 9). Nevertheless, it can be noticed that in both the trials N recovery values were clearly higher when pigeon bean was used as the cover crop. On the contrary, in 2003–2004 tomato following brown mustard assimilated a smaller N amount than control tomato crop (Table 9), a situation similar to that observed by Mazzoncini et al.[33] in sunflower. Although brown mustard residues showed a C/N ratio and a N content (Table 4) favorable to a rapid mineralization and consequent release of mineral N[40,41], probably they also contained some compounds able to slow down their mineralization rate[42]. For example, soluble polyphenols have such an effect as they form complexes with proteins, thus making them inaccessible to microorganisms[43]. In another species of *Brassica* (*B. napus* L.), Trinsoutrot et al.[44] found that the leaves, characterized by a low C/N ratio but also by a high concentration of soluble polyphenols, caused N immobilization at the start of decomposition, but net N mineralization occurred afterwards.

In our research, a very low value for N recovery, although not negative ($0.63\,kg\,ha^{-1}$ and 1.49%), was detected for rye in 2004–2005 (Table 9). In this year, N recovery by tomato crop following flax was not determined because of the very poor biomass produced by this species, responsible for a negligible N supply (Table 4). Indeed, the resulting N recovery percent value would have given the erroneous idea of a great efficiency of this species in supplying N to tomato.

Comparing N recovery detected in 2003–2004 with that of 2004–2005, it appears that in the second year, in

Table 9. Recovery by tomato crop of N supplied by the compared cover crops.

Species	2003–2004		2004–2005		Average (2003–2004/2004–2005)	
	N recovery ($kg\,ha^{-1}$)	N recovery (%)	N recovery ($kg\,ha^{-1}$)	N recovery (%)	N recovery ($kg\,ha^{-1}$)	N recovery (%)
Oats + barley	25.08	12.37	14.53	22.60	19.81ab	14.84
Rye	20.28	12.28	0.63	1.04	10.46b	9.28
Brown mustard	−8.38	–	5.76	10.84	−1.31b	–
Flax	23.77	16.16	–[1]	–[1]	–[1]	–[1]
Pigeon bean	46.62	19.25	64.04	35.97	55.33 a	26.33
Control	–	–	–	–	–	–
Significance	ns	ns	ns	ns	*	ns

In each column, means followed by the same letter are not significantly different at $P \leq 0.05$ (*) and $P \leq 0.01$ (**) (LSD test).
[1] Explanation in the text.

Table 10. Characteristics of marketable fruits produced by tomato crop following the compared cover crops.

Species	2003–2004				2004–2005				
	Average fresh weight (g)	N content ($g\,kg^{-1}$)	Firmness (kPa)	Soluble sugars (°Brix)	Average fresh weight (g)	N content ($g\,kg^{-1}$)	pH	Firmness (kPa)	Soluble sugars (°Brix)
Oats + barley	86.76	35.30	206.92a	3.86	93.79	20.71ab	4.42	220.65	5.34
Rye	76.35	35.29	187.31abc	3.55	80.94	18.37b	4.45	209.86	5.23
Brown mustard	80.66	31.23	190.25ab	3.54	80.96	18.76b	4.49	215.75	5.28
Flax	85.52	33.24	190.25ab	3.51	80.19	17.45b	4.48	209.86	5.19
Pigeon bean	79.97	35.28	169.66bc	4.04	85.30	22.52a	4.51	196.13	5.33
Control	81.82	35.63	167.69c	3.72	73.37	17.13b	4.48	207.90	5.24
Significance	ns	ns	**	ns	ns	*	ns	ns	ns

In each column, means followed by the same letter are not significantly different at $P \leq 0.05$ (*) and $P \leq 0.01$ (**) (LSD test).

conditions of N shortage in the soil, despite the poorer biomass production, N efficiency of most of the cover crops was higher, that is, tomato recovered a greater amount of N supplied by cover crops. N recovery percent values, with the exception of rye, were actually much higher than that in 2003–2004 (Table 9).

The average N recovery values between 2003–2004 and 2004–2005 are shown as they pointed out well the differences among the compared cover crops. Actually, in this case pigeon bean corresponded to a value ($55.33\,kg\,ha^{-1}$) significantly higher than rye and brown mustard (Table 9).

Fruit quality. Average fresh weight, N content, pH, firmness and soluble sugar content (°Brix) were considered as fruit qualitative parameters (Table 10). Fruit average fresh weight and soluble sugar content did not show any statistically significant differences among the treatments in both the years; that result may indicate the predominance of the varietal factor over the cover crop effect in influencing these parameters. In 2003–2004, control fruits showed a lower firmness than fruits produced by tomato following oats and barley mixture, brown mustard and flax; a firmness value closer to that of control fruits was detected in tomatoes grown after pigeon bean, where the higher N supply may have influenced this parameter negatively. In fact, a high N application may reduce tomato fruit firmness[45,46]. Nevertheless, no differences in fruit N content were noticed. On the contrary, in 2004–2005 tomato fruits showed a significantly higher N content when pigeon bean was used as the cover crop. Finally, also for fruit pH, measured only in the second year, no differences among the treatments were detected.

Conclusions

Cover crops can be useful in organic farming to reduce the dependence on external inputs, particularly chemical fertilizers, thanks to the significant amounts of ready-to-use N they provide cash crops with.

In the environmental conditions in which our research was conducted, the leguminous species (pigeon bean) proved to be the most efficient cover crop in supplying N to the soil, in spite of a low biomass production. The particular mineralization rate of pigeon bean residues, with a peak of $N\text{-}NO_3$ 1–2 months after green manure turning under, may satisfy the N requirement of a following cash crop, like tomato, in the vegetative growth stage and sustain production without any fertilizer addition. As for fertilizers[2], it is likely that the beneficial effect of green

manure on the cash crop is more evident in soils that are not very fertile.

Also in conventional or low-input farming the possibility of reducing the amount of chemical fertilizers, resulting from the use of cover crops, is advantageous, as it may lower the economic[47] and environmental costs of crop management.

Acknowledgements. This research was founded by ARSIA, Regione Toscana (Project 'L'agricoltura biologica e biodinamica toscana relativa a sistemi finalizzati alle produzioni vegetali'—AGRIBIO). We thank all the staff of Bonamici Farm and of the Rottaia Experimental Station of DAGA in San Piero a Grado (Pisa) for their precious collaboration.

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Renewable Agriculture and Food Systems: 24(2); 102–119 doi:10.1017/S1742170509002555

Long-term economic performance of organic and conventional field crops in the mid-Atlantic region

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Accepted 23 March 2009 **Research Paper**

Abstract

Interest in organic grain production is increasing in the United States but there is limited information regarding the economic performance of organic grain and forage production in the mid-Atlantic region. We present the results from enterprise budget analyses for individual crops and for complete rotations with and without organic price premiums for five cropping systems at the US Department of Agriculture–Agricultural Research Service (USDA–ARS) Beltsville Farming Systems Project (FSP) from 2000 to 2005. The FSP is a long-term cropping systems trial established in 1996 to evaluate the sustainability of organic and conventional grain crop production. The five FSP cropping systems include a conventional, three-year no-till corn (*Zea mays* L.)–rye (*Secale cereale* L.) cover crop/soybean (*Glycine max* (L.) Merr)–wheat (*Triticum aestivum* L.)/soybean rotation (no-till (NT)), a conventional, three-year chisel-till corn–rye/soybean–wheat/soybean rotation (chisel tillage (CT)), a two-year organic hairy vetch (*Vicia villosa* Roth)/corn–rye/soybean rotation (Org2), a three-year organic vetch/corn–rye/soybean–wheat rotation (Org3) and a four- to six-year organic corn–rye/soybean–wheat–red clover (*Trifolium pratense* L.)/orchard grass (*Dactylis glomerata* L.) or alfalfa (*Medicago sativa* L.) rotation (Org4+). Economic returns were calculated for rotations present from 2000 to 2005, which included some slight changes in crop rotation sequences due to weather conditions and management changes; additional analyses were conducted for 2000 to 2002 when all crops described above were present in all organic rotations. Production costs were, in general, greatest for CT, while those for the organic systems were lower than or similar to those for NT for all crops. Present value of net returns for individual crops and for full rotations were greater and risks were lower for NT than for CT. When price premiums for organic crops were included in the analysis, cumulative present value of net returns for organic systems (US$3933 to 5446 ha^{-1}, 2000 to 2005; US$2653 to 2869 ha^{-1}, 2000 to 2002) were always substantially greater than for the conventional systems (US$1309 to 1909 ha^{-1}, 2000 to 2005; US$634 to 869 ha^{-1}, 2000 to 2002). With price premiums, Org2 had greater net returns but also greater variability of returns and economic risk across all years than all other systems, primarily because economic success of this short rotation was highly dependent on the success of soybean, the crop with the highest returns. Soybean yield variability was high due to the impact of weather on the success of weed control in the organic systems. The longer, more diverse Org4+ rotation had the lowest variability of returns among organic systems and lower economic risk than Org2. With no organic price premiums, economic returns for corn and soybean in the organic systems were generally lower than those for the conventional systems due to lower grain yields in the organic systems. An exception to this pattern is that returns for corn in Org4+ were equal to or greater than those in NT in four of six years due to both lower production costs and greater revenue than for Org2 and Org3. With no organic premiums, present value of net returns for the full rotations was greatest for NT in 4 of 6 years and greatest for Org4+ the other 2 years, when returns for hay crops were high. Returns for individual crops and for full rotations were, in general, among the lowest and economic risk was, in general, among the highest for Org2 and Org3. Results indicate that Org4+, the longest and most diverse rotation, had the most stable economic returns among organic systems but that short-term returns could be greatest with Org2. This result likely explains, at least in part, why some organic farmers in the mid-Atlantic region, especially those recently converting to organic methods, have adopted this relatively short rotation. The greater stability of the longer rotation, by contrast, may

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explain why farmers who have used organic methods for longer periods of time tend to favor rotations that include perennial forages.

Key words: organic grain crops, economic performance, enterprise budget analysis, organic crop rotation, long-term agricultural research

Introduction

The number of certified organic crop acres in the United States increased by an average of 24% per year between 1992 and 2005[1]. Since meat and milk are the fastest growing sectors of the organic industry, demand for organic grains is high and organic grain prices have been about double those of conventional grains since 2000, even as conventional grain prices soared and decreased again during the period 2006 to 2008[2–5]. Organic price premiums have attracted the interest of an increasing number of conventional grain farmers who are considering adopting or have recently adopted organic production methods. Many farmers and agricultural professionals, however, are uncertain about the profitability and risk associated with organic grain and forage production. In the US, Federal Government Agencies, State Departments of Agriculture and Cooperative Extension personnel have been increasing their programming in organic grain and forage production and marketing to facilitate informed decision-making about organic grain and forage production opportunities[1,6–8].

Recent studies report that corn, soybean and wheat yields in organic systems in the Midwest and the mid-Atlantic regions of the US, and corn yield in California tend to be lower than or similar to those in conventional systems[9–16]. Production costs tend to be lower in organic than in conventional systems[15,17–21]. Net returns are similar to or lower than in conventional systems when no organic price premiums are included, depending on whether reductions in yield and therefore revenue are greater or lesser than cost reductions[10,17,20,22,23]. Hanson et al.[17] and Hanson and Musser[23] found that organic systems in Pennsylvania had lower risk than conventional systems. In almost all cases, when organic price premiums were included in the analyses, organic systems outperformed conventional systems[15,18–21,23,24], even when price premiums were set at 50% of existing levels[19,24].

The impact of crop rotation length and diversity on economic performance, which can impact agronomic performance[13,16], has been studied in the upper US Midwest and in Canada for organic systems. These studies provide mixed results, indicating that the impact of crop rotation length and diversity on economic performance depends on specific crops used in a particular rotation and on location. In southern Minnesota, returns were greater and risk was lower for a 4-year corn–soybean–oats/alfalfa–alfalfa rotation than a 2-year corn–soybean rotation when managed using organic practices with no organic premiums[19]. Archer and Kludze[24], also in southern Minnesota, showed that risk was lower for a 2-year organic corn–soybean rotation than for a 4-year organic corn–soybean–spring wheat/alfalfa–alfalfa rotation using a stochastic simulation approach. Archer et al.[15] showed no differences in net present value of returns between the same 2-year and 4-year rotations although production costs were lower for the 4-year than for the 2-year rotation. Delate et al.[18] showed no differences in economic performance between a 3-year corn–soybean–oat/alfalfa and a 4-year corn–soybean–oat/alfalfa–alfalfa rotation in Iowa. In Alberta, Canada, returns were greater for a 4-year wheat–field pea (*Pisum sativum* L.)–oilseed [canola (*Brassica napus* L.) or flax (*Linum usitatissimum* L.)]–sweet clover (*Melilotus officinalis* [L.] Lam.) rotation than a 2-year wheat–sweet clover organic rotation but were least for a 4-year wheat–barley (*Hordeum vulgare* L.) and field pea–fenugreek (*Trigonella foenum-graecum* L.) and ryegrass (*Lolium multiflorum* Lam.)–oilseed and berseem clover (*Trifolium alexandrinum* L.) organic rotation, for which compost, hauling and application costs were high[20].

Results from the mid-Atlantic region show that economic returns to management for organic grain production can be competitive with a conventional tillage corn–soybean–corn–corn–soybean rotation even without organic price premiums[17,22,23]. However, organic systems outperformed conventional systems only from 1986 to 1990 when the crop rotation in the organic system was corn–small grain/soybean–small grain/red clover and not from 1991 to 1995 when the crop rotation in the organic system was vetch/corn–rye/soybean–wheat. Additional information is needed for the Coastal Plains portion of the mid-Atlantic region of the United States, where our study site is located. This region, where 29% of land remains under agricultural production[25], encompasses portions of New Jersey, Pennsylvania, Delaware, Maryland, Virginia and North Carolina. Also, previous results from the mid-Atlantic region have not explored the impact of crop rotation length and diversity on economic performance of organic systems or compared organic systems with conventional no-till systems, which are an important management system in the mid-Atlantic region.

We report here on six years of economic data from a long-term cropping systems study in Maryland, the USDA–ARS Beltsville Farming Systems Project (FSP), which was established in 1996 to evaluate the sustainability of organic and conventional cropping systems. Earlier results from this site, covering the years 1996 through 2005, showed that corn and soybean yields were, in general, greater in conventional than in organic systems, that corn yield among organic systems increased with increasing rotation length and diversity, and that there were no consistent differences

Table 1. Overview of cropping systems management at the USDA-ARS Beltsville FSP.

	Cropping systems				
	Conventional no-till 3-year rotation	**Conventional chisel till 3-year rotation**	**Organic 2-year rotation**	**Organic 3-year rotation**	**Organic 4+-year rotation**
Crop rotation[1]	C–r/S–W/S	C–r/S–W/S	v/C–r /S	v/C–r/S–W/v	C–r/S–W/PF
Primary tillage[2]	None	Ch	D, MB, Ch	D, MB, Ch	D, MB, Ch
Weed control[3]	Herbicides	Primary tillage, herbicides	Primary tillage, RH, RC	Primary tillage, RH, RC	Primary tillage, RH, RC
Fertility[4]	N, P, K	N, P, K	GM, AM, K	GM, AM, K	GM, AM, K

[1] C, corn; S, soybean; W, wheat; W/S, wheat followed by double-cropped soybean; PF, perennial forage crop, either red clover+orchard grass (2000–2001) or alfalfa (2001–2005); r, rye cover crop; v, hairy vetch green manure cover crop. No-till and chisel till rotations in 2000 were C–W/S (see Table 2).
[2] D, disk; MB, moldboard plow; Ch, chisel plow. See Tables 3–5 for details regarding specific implements used for each crop.
[3] RH, rotary hoe; RC, row cultivator; both of which were used for corn and soybean only; rotary hoe was not used from 2000 to 2002 in Org2 and Org3 since a reduced tillage system was used then, as described in the text.
[4] N included ammonium nitrate, urea ammonium nitrate; P was triple super phosphate; K was potassium chloride in conventional systems and potassium sulfate in organic systems; rates are provided in Tables 3–5; GM, green manures; AM, animal manures.

in wheat yield among systems[16]. Those results also showed that, on average, 73, 23 and 4% of the difference in corn yield between conventional and organic systems was associated with low nitrogen availability, weed competition and corn population, respectively. Differences in soybean yields resulted solely from weed competition. In this paper, we report on production costs and economic performance of the systems with and without organic price premiums during 6 years following the organic transition period. These years were chosen for this analysis because inconsistent management among field replicates and a severe drought from 1997 to 1999 made comparisons of rotations during earlier years problematic.

Materials and Methods

Study site

The study site is 16 ha in size and is at the western edge of the Atlantic Coastal Plain at the USDA–ARS Beltsville Agricultural Research Center in Maryland. The dominant soil types are Christiana (fine, kaolinitic and mesic Typic Paleudults), Matapeake (fine-silty, mixed, semiactive and mesic Typic Hapludults), Keyport (fine, mixed, semiactive, mesic and Aquic Hapludults) and Mattapex (fine-silty, mixed, active and mesic Aquic Hapludults) silt loams. The site had not been tilled for 11 years prior to plot establishment in 1996. The 30-year average annual precipitation at the site is 1110 mm, distributed evenly through the year. Average annual temperature is 12.8°C.

Cropping systems and cultural practices

The FSP, which was established in 1996, includes two conventional systems and three organic systems (Table 1) that reflect typical rotations used by farmers in the mid-Atlantic region. Cropping systems were selected after consulting with regional grain farmers, including organic farmers; extension agents, specialists and researchers from the University of Maryland, Delaware State University and the University of Delaware; farm managers from various regional governmental and non-governmental organizations; and a representative of the National Center of Appropriate Technology's Appropriate Technology Transfer for Rural Areas agency. Management practices are reviewed annually by a group of University of Maryland extension specialists and Beltsville Agricultural Research Center farm managers and by a separate, informal group of organic farmers from Maryland. Any changes in management (e.g., crop variety selection and herbicide program) are made in consultation with these groups. The site is not certified organic because the distance between the conventional and organic plots (usually 2 m; see below) does not meet certification requirements; however, organic management practices at the site follow USDA National Organic Program practices.

The planned crop rotation in the two conventional systems is a three-year corn–rye cover crop/full-season soybean–wheat/double-crop soybean rotation, a common rotation in this area (Table 2). One system uses no-till (NT) management and the other uses chisel tillage (CT) for primary tillage. Both are common practices in the region. The three organic cropping systems differ from each other in crop rotation length and complexity: a two-year hairy vetch/corn–rye/soybean rotation (Org2), a three-year vetch/corn–rye/soybean–wheat/vetch rotation (Org3) and a four- to six-year corn–rye/soybean–wheat/red clover/orchard grass–red clover/orchard grass or alfalfa–alfalfa–alfalfa–alfalfa rotation (Org4+). The designation Org4+ is used to indicate a rotation length of four to six years. From 1996 to 2000 the rotation was 4 years in length and red clover/orchard grass was the forage crop. Beginning in 2000, alfalfa was planted as the forage crop and a transition from a four- to a six-year rotation was initiated. This change was made because alfalfa provides more nitrogen to

Table 2. Crops[1] present in each subplot of the five cropping systems of the USDA-ARS Beltsville FSP during the study period, 2000 to 2005. The number of subplots for a given cropping system reflects the number of years in the crop rotation. Cover crops planted in fall 1999 are included and those planted in the fall 2005 are not included because costs of establishing cover crops in the fall were allocated to the succeeding cash crop. By similar reasoning, wheat planted in fall 1999 is included, while wheat planted in fall 2005 is not included.

Cropping system	Subplot	Crops present in given years						
		1999	2000	2001	2002	2003	2004	2005
No-till	1	–/w	W/S	C/r	r/S	S	C/r	r/S/–
	2	–	C/r	r/S/w	W/S	C/r	r/S/w	W/S
	3	–	–/w	W/S	C/r	r/S	S	C/–
Chisel till	1	–/w	W/S	C/r	r/S	S	C/r	r/S/–
	2	–	C/r	r/S/w	W/S	C/r	r/S/w	W/S
	3	–	–/w	W/S	C/r	r/S	S	C/–
Organic 2-year	1	–/r	r/S/v	v/C/r	r/S	C/r	r/S	C/r
	2	–/v	v/C/r	r/S/v	v/C/r	r/S	C/r	r/S/–
Organic 3-year	1	–/w	W/v	v/C/r	r/S	–/v	v/C/r	r/S/–
	2	–/v	v/C/r	r/S/w	W/v	v/C/r	r/S	SG[2]/–
	3	–/r	r/S/w	W/v	v/C/r	r/S	SG[2]/v	v/C/–
Organic 4+-year	1	–	h/C/r	r/S/w	W/a	A	SG/a	A
	2	–/r	r/S/w	W/a	A	A	SG/a	a/C/–
	3	–/w	W/h	H	h/C/r	r/S	SG/a	A
	4	–	–/a	a/C/r	S	f/a	SG/a	A
	5	–	H/a	A	A	a/C/r	S	SG/–
	6	–	–	–/a	A	A	C/r	S/–

[1] A, alfalfa; C, corn; H, red clover plus orchard grass that was harvested as hay; r, rye cover crop; S, soybean; SG, Sudan grass; v, hairy vetch cover crop; W, wheat. Capital letters indicate crops that were harvested in a given year; lower case letters indicate crops that were planted in the fall and those that served as green manures.
[2] Not included in economic analyses, as described in the text.

a succeeding crop than does a clover-grass mix, and corn crops in this rotation showed signs of nitrogen limitation. In 2001, both types of forage crop (in separate plots) were present as part of this transition; from 2002 to 2005 alfalfa was the only forage crop present (Table 2).

The organic cropping systems reflect typical crop rotations and practices used by farmers in the mid-Atlantic area (personal communication, E. Dengler, Natural Resources Conservation Service, Maryland; C. Lawrence, Natural Resources Conservation Service, Virginia; E. Fry, L. Howard, N. Maravell, B. Mason, A. Reed and S. Ward, Maryland organic farmers). The 2-year rotation is considered organic-compliant through the state of Maryland organic certification program since it includes four crops (including two cover crops) in two years (personal communication, W. Rawlings, Maryland Department of Agriculture).

Each crop in each crop rotation was represented every year (with exceptions noted below and in Table 2). Cropping systems are replicated four times in a split-plot design with system assigned to whole plots and crop rotation phase assigned to subplots. For example, in Org3 there are three subplots. In a given year, one subplot is planted to corn in the spring following a hairy vetch cover crop that was planted the previous fall, followed by a rye cover crop in the fall (e.g., subplot 1 in 2001, Table 2). A second subplot is planted to soybean in the spring following the rye cover crop and is then planted to wheat in the fall (e.g., subplot 2 in 2001). In a third subplot, wheat that was planted the previous fall is harvested in the summer and vetch is planted in late August or early September (e.g., subplot 3 in 2001). Each subplot is 9.1 m wide and 111 m long; there is a grassed alleyway 2 m in width between most whole plots. Typical field operations are presented in Tables 3–5 for corn, soybean and wheat, respectively. Commercial-scale farm equipment was used for all field management operations.

Management changes

Management practices within some cropping systems were changed (Tables 1 and 2) to adapt to evolving conditions, an approach that might more closely reflect farmer decisions than does a rigid adherence to a predetermined rotation sequence, which is the typical approach in experiment station settings. For example, the crop rotation in the two conventional systems was a 2-year corn–wheat/double-crop soybean rotation until 2000. The rotation was expanded to the current 3-year rotation in 2001 by including a full-season soybean crop after the corn to reduce diseases caused by various organisms (including Septoria leaf and glume blotches, tan spot and scab) in wheat following corn in the NT system[26]. At the time, wheat grain prices were low and using fungicides was deemed uneconomical. Both the 2- and the 3-year rotations are common in the mid-Atlantic region. Also, as previously

Table 3. Typical field operations and rates of application of materials for corn in five cropping systems at the USDA-ARS Beltsville FSP, Beltsville, Maryland.

	Cropping systems				
Field operation	**Conventional no-till 3-year rotation**	**Conventional chisel till 3-year rotation**	**Organic 2-year rotation**	**Organic 3-year rotation**	**Organic 4+-year rotation**
Disk			x	x	
Plant legume cover crop (45 kg seed ha^{-1})			x	x	
Apply 2,4-D[1] herbicide (0.56 kg a.i. ha^{-1})	x				
Broadcast NH_4NO_3 (48 kg N ha^{-1})	x	x			
Broadcast K fertilizer[2]	x	x	x	x	x
Chisel plow		x			
Apply animal manure[3]			x	x	x
Moldboard plow[4]			x	x	x
Disk or field cultivator		2x	2x	2x	2x
Plant corn (67,600 seeds ha^{-1})	x	x	x	x	x
Apply starter fertilizer (17–15–14 kg ha^{-1} N-P-K)	x	x			
Apply herbicide[5]					
S-metolachlor	1.90 kg a.i. ha^{-1}	1.74 kg a.i. ha^{-1}			
Atrazine	1.94 kg a.i. ha^{-1}	1.78 kg a.i. ha^{-1}			
Paraquat	0.52 kg a.i. ha^{-1}				
Apply insecticide[6] (0.11 kg a.i. ha^{-1})	x	x			
Rotary hoe[7]			2x	2x	2x
Side dress urea ammonium nitrate subsurface (96 kg N ha^{-1})	x	x			
Inter-row cultivation			2x	2x	2x
Harvest	x	x	x	x	x

[1] 2,4-dichlorphenoxyacetic acid.
[2] KCl in NT and CT applied at 46 kg K_2O ha^{-1}; K_2SO_4 in Org2 and Org3 applied at 37 kg K_2O ha^{-1} and at 60 kg K_2O ha^{-1} in Org4+, all in accordance with soil test results.
[3] Broiler litter applied at 2240 and 6720 kg ha^{-1} in Org2 in 2000 and 2003, respectively; at 2240 and 4480 kg ha^{-1} in Org3 in 2000 and 2003, respectively; and at 5600 kg ha^{-1} in Org4+ in 2000. Layer litter applied at 6720 kg ha^{-1} in Org2 and Org4+ in 2004 and 2005 and in Org3 in 2004. Dairy manure slurry applied in Org4+ in 2002 at 124,000 liters ha^{-1}. Manure rates were adjusted in accordance with measured or visually estimated cover crop biomass levels and are thus different by year and by system. Average nutrient content of animal manures was 2.51% N, 2.37% P_2O_5 and 1.99% K_2O.
[4] Moldboard plow used in Org2 and Org3, 2003 to 2005 and in Org4+, 2000 to 2005. There was no primary tillage in Org2 and Org3 from 2000 to 2002; instead, the vetch cover crop was crushed using a roller in May and corn was planted directly through the residue using a high-residue no-till drill.
[5] S-metolachlor, 2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl) acetamide; atrazine, 6-chloro-*N*-ethyl-*N*′-(1-methylethyl)-1,3,5-triazine-2,4-diamine); paraquat, 1,1′-dimethyl-4,4′-bipyridinium ion. Beginning in 2004 simazine (6-chloro- *N*, *N*′-diethyl-1,3,5-triazine-2,4-diamine) was applied at 1.78 and 1.22 kg a.i. ha^{-1} in NT and CT, respectively, to address late season grass emergence and metolachlor and atrazine concentrations were reduced to 1.33 and 0.34 kg a.i. ha^{-1}, respectively.
[6] Permethrin, (3-phenoxyphenyl)methyl cis,trans-(+−)-3-(2,2-dichloroethenyl)-2,2-dimethylcyclopropanecarboxylate, applied in NT and CT in 2004 and 2005 to control cutworms (Family Noctuidae).
[7] Rotary hoe not used from 2000 to 2002 in Org2 and Org3 in accordance with the reduced tillage system in place during these years (see footnote 4).

described, Org4+ was expanded from a 4- to a 6-year rotation beginning in fall 2000. Despite these changes, the fundamental differences among the five systems remained distinct from each other from 2000 through 2005, i.e., the NT and CT were managed using practices common in the region and the three organic systems differed in crop rotation length and complexity, while relying on cultivation for weed control and on organic sources for nitrogen inputs.

Corn. In the organic systems, the hairy vetch cover crop, which was drilled after harvest of the previous soybean (Org2) or wheat (Org3) crop, or the perennial forage crop (Org4+) served as a green manure to supply nitrogen for corn. Animal manure (usually poultry litter; Table 3) was applied in the spring to supplement green manure nitrogen in 2000 in Org2; in 2000, 2003 and 2004 in Org3; and in 2000, 2002 and 2005 in Org 4+ when visual assessment and/or biomass sampling of green manure crop biomass suggested there was insufficient legume cover to provide adequate nitrogen. In addition, animal manure alone was applied in spring 2003, 2004 and 2005 in Org2 when wet soil conditions the previous fall did not allow timely planting of the vetch cover crop,

Table 4. Typical field operations for full-season soybean in five cropping systems at the USDA-ARS Beltsville FSP, Beltsville, Maryland.

	Cropping systems				
Field operation	**Conventional no till 3-year rotation**	**Conventional chisel till 3-year rotation**	**Organic 2-year rotation**	**Organic 3-year rotation**	**Organic 4+-year rotation**
Mow corn stalks[1]	x	x	x	x	x
Plant rye cover crop[1] (125 kg seed ha^{-1})	x	x	x	x	x
Broadcast K fertilizer[2]	x	x	x	x	x
Apply paraquat[3] (0.63 kg a.i. ha^{-1})	x				
Chisel plow		x	x	x	x
Disk or Field cultivator[4]		x	2x	2x	2x
Plant soybean (526,400 seeds ha^{-1})	x	x	x	x	x
Apply glyphosate[5] (1.68 kg a.i. ha^{-1})	x	x			
Rotary hoe[6]			2x	2x	2x
Inter-row cultivation			2x	2x	2x
Harvest	x	x	x	x	x

[1] Rye was not planted in NT and CT in fall 1999.
[2] KCl applied in NT and CT at 76 and 104 kg K_2O ha^{-1}; K_2SO_4 applied in Org2 and Org3 at 37 kg K_2O ha^{-1} and in Org4+ at 76 kg K_2O ha^{-1}, all in accordance with soil test results.
[3] 1,1′-dimethyl-4,4′-bipyridinium ion.
[4] Chisel plow used for primary tillage in organic systems from 2003 to 2005; there was no primary tillage in the organic systems from 2000 to 2002; instead, the rye cover crop was mowed in May and soybean was planted directly through the residue using a high-residue no-till drill.
[5] *N*-(phosphonomethyl)glycine.
[6] Rotary hoe not used from 2000 to 2002 in organic systems in accordance with the reduced tillage system in place during these years (see footnote 4).

Table 5. Typical field operations for wheat in four cropping systems at the USDA-ARS Beltsville FSP, Beltsville, Maryland.

	Cropping system			
Field operation	**Conventional no till 3-year rotation**	**Conventional chisel till 3-year rotation**	**Organic 3-year rotation**	**Organic 4+-year rotation**
Apply poultry litter[1] (6300 kg ha^{-1})			x	x
Disk		2x	2x	2x
Plant wheat (160 kg seed ha^{-1})	x	x	x	x
Apply N fertilizer (28 kg N ha^{-1})	x	x		
Apply N fertilizer (80 kg N ha^{-1})	x	x		
Apply herbicides[2]	x	x		
Harvest	x	x	x	x

[1] Poultry litter incorporated into soil in fall except in fall 1999; topdressed in March 2000. Average nutrient content of poultry litter was 2.97% N, 3.00% P_2O_5 and 2.32% K_2O.
[2] Trifensulfuron, 3-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl] amino]sulfonyl]-2-thiophenecarboxylic acid applied at 18 g a.i. ha^{-1}; tribenuron, 2-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)methylamino] carbonyl]amino]sulfonyl]benzoic acid applied at 9 g a.i. ha^{-1}.

and in spring 2004 in Org4+ since the wet weather in 2003 killed the established alfalfa crop. Manure was used conservatively because of excessive soil P at this site (169 ppm Mehlich I P_2O_5; >103 ppm is considered excessive in Maryland). High soil P is common in the mid-Atlantic region and has raised concerns among organic farmers in the area about the ability to maintain yields in the long-term without further increasing soil P levels (personal communication A. Cooper, E. Fry, N. Maravell, B. Mason and C. Spies, Maryland organic farmers). Corn was planted 2–3 weeks later in the organic than in the conventional systems to maximize green manure crop biomass and N content and to allow weeds to germinate prior to final seedbed preparation.

From 2000 to 2002 a reduced tillage system was used in Org2 and Org3[27]. Instead of primary tillage, the hairy vetch cover crop was crushed using a corn stalk chopper after flowering and left on the soil surface as a mulch; corn was then planted using a no-till planter, and a high residue cultivator was used two to three times for weed control.

A more traditional organic management protocol was used from 2003 to 2005 to address weed problems that occurred in the reduced tillage system[16].

Soybean. Full-season soybean was planted two to three weeks later in the organic systems than in the conventional systems to allow weeds to germinate prior to final seedbed preparation. When a reduced tillage system was used in the organic systems from 2000 to 2002, the rye cover crop was killed by mowing after flowering, soybean was planted using a no-till planter and a high residue cultivator was used for weed control.

Winter wheat. Due to wet soil conditions, wheat was not planted in any system in the fall of 2002 and 2003 and in the organic systems in the fall of 2004 (Table 2). Thus, full-season soybean was planted instead of double-cropped soybean in NT and CT in 2003 and 2004. In Org3 and Org4+, a Sudan grass (*Sorghum vulgare* var. *sudanense* Hitchc.) silage crop was planted in plots in which wheat would have been harvested in 2004 and 2005. The Sudan grass in Org3 was not included in the economic analyses because a forage crop was considered too much of a deviation in this otherwise grain-based rotation, i.e., a farmer who uses Org3 would not likely own the equipment necessary to cut and harvest a forage crop. However, all three subplots were included in the economic analyses for Org3, reflecting loss of the wheat crop.

Forage crops. The perennial forage crops in Org4+ were sown in late August or early September and were harvested up to four times each year. All alfalfa died in late summer 2003 due to wet soil conditions. All plots that were planned to be in alfalfa in 2004 were planted to Sudan grass in late spring, the Sudan grass was harvested as haylage in late summer, and alfalfa was replanted in the fall (Table 2). The Sudan grass crop was included in the analyses for Org4+ since this system already included forage crops.

Enterprise analyses

Enterprise budgets were constructed for each crop (except for Sudan grass in Org3 as noted above) for each year from 2000 to 2005 based on field activity records. Production costs included costs of input materials (pesticide, fertilizer, seed, lime and manure) and field operations (tillage, planting, materials application, cultivation, harvesting and hauling). Costs of establishing cover crops were allocated to the succeeding cash crop. Field operation costs, including the cost of liquid dairy manure and application (used in 2002 for corn in Org4+), are based on Maryland custom work charges[28], which include labor and machinery operating costs (fuel, lubrication and repairs) and a portion of the fixed costs of machinery ownership. All costs were adjusted to 2006 dollars, using the index for crop farm input prices published by the USDA National Agricultural Statistics Service[29]. Poultry litter cost was estimated at US$11 Mg^{-1} based on prices paid by local farm managers (personal communication, D. Shirley, USDA–ARS; N. Maravell, Maryland organic farmer), and assuming that the manure source is located near the fields where it is applied, i.e., a minimal transportation cost is included in the cost of the material. The cost of management and the fixed costs associated with land and building ownership are assumed to be the same for each cropping system and therefore were not included in the analysis.

Corn, wheat and soybean were harvested as dry grain. In the conventional systems wheat straw was harvested. Since organic farmers in Maryland often do not harvest wheat straw, preferring instead to use the straw to build soil quality and reduce nutrient, especially potassium, exports (personal communication, N. Maravell, Maryland Organic Food and Farming Association; E. Fry; Maryland organic farmer), we did not harvest the wheat straw in this study. Forage crops were usually harvested as hay, but also as haylage or greenchop depending on farm management needs at the time; appropriate prices were used in the analysis (Table 6). All harvested crops were treated as cash crops, contributing to revenue (defined as crop price times yield). In the mid-Atlantic region, the vast majority of organic grain crops are grown and sold as feed- rather than food-grade grain due to the extra challenges of growing and marketing food grade crops, the proximity of organic animal industries, and the lack of brokers to help coordinate the purchase and sale of organic food grade grains (personal communication, R. Hood, L. Howard and N. Maravell, Maryland organic farmers; K. Fedor and W. Rawlings, Maryland Department of Agriculture; J. Rhodes, Maryland Cooperative Extension).

Economic returns were calculated on a dollars per hectare basis by subtracting costs from revenue. Because management, land and building costs were not included in the analysis, the net returns obtained here are more correctly termed 'returns to management, land and buildings'. Out of these returns, farmers could expect to make payments toward such long-term costs as buildings, machinery, land, etc. Average statewide prices for conventionally produced corn, soybean, wheat, hay and straw were obtained from the Maryland Office of the US Department of Agriculture's National Agricultural Statistics Service[30] (Table 6). Prices for organically produced crops, which are based on annual midpoint prices for US organic corn, wheat and soybeans[2,3], are also included in Table 6. These prices were comparable to prices received in the Maryland area at the time (personal communication, S. Smelter, Kreamer Feed, Inc., Kreamer, PA). No organic premiums were used to calculate returns for hay, haylage and greenchop since forage products were not of the quality required by the organic dairy industry (personal communication, L. Vough, University of Maryland). All economic analyses were carried out twice: once assuming that organic price premiums were obtained for organic corn, soybean and wheat, and then using conventional prices for both conventional and organic crops. While organic crop prices were about twice those of conventional prices from 2000 to

Table 6. Conventional and organic crop prices used to assess the economic performance of five cropping systems at the USDA-ARS Beltsville FSP, Beltsville, Maryland, 2000 to 2005.

Crop	Price	Crop price (US$ Mg^{-1})[1]						Average price premium (%)[2]
		2000	2001	2002	2003	2004	2005	
Corn	Conventional	90	93	105	102	82	82	–
	Organic	171	142	185	199	224	284	118
Soybean	Conventional	209	192	195	225	294	231	–
	Organic	590	540	532	527	552	551	138
Wheat	Conventional	120	115	117	140	126	135	–
	Organic	254	253	234	221	213	231	111
Wheat straw[3]	Conventional	1.97	2.09	2.12	2.04	1.97	2.13	–
Mixed hay	Conventional	119	141	–	–	–	–	–
Alfalfa hay	Conventional	–	160	179	141	137	165	–
Sudan haylage	Conventional	–	–	–	–	50	50	–
Alfalfa haylage	Conventional	50	58	56	–	–	–	–
Alfalfa greenchop	Conventional	–	28	29	–	–	–	–

[1] Conventional prices obtained from the Maryland Office of USDA–NASS[30]. Organic prices obtained from Streff and Dobbs[2] for 2000 to 2003, and Hamilton[3] for 2004 and 2005.
[2] For years when all five cropping systems were represented: for corn, 2000–2005; for soybean, 2001–2005; for wheat, 2000–2002.
[3] US$ bale^{-1}.

2005 (Table 6), and remained so as of March 2009[4,5], these premiums could decline if new production outpaces increases in demand[8,19,24]. Conducting analyses using conventional prices illustrates a baseline measurement and a potential future scenario.

Annual returns are expressed in present value terms to account for the time value of money[15] over the 6-year study span. Compounded values were calculated as

$$CV = V*(1+r)^t,$$

where CV is the compounded value of net returns, V is uncompounded value of net returns, r is interest rate and t is an index of years from 0 to 5, running backwards from 2005 to 2000. Thus $t = 5$ represents 2000 and $t = 0$ represents 2005. An average interest rate of 6% was chosen for this analysis. The net present value of returns for a given enterprise was calculated by summing the compounded returns for the relevant years.

Risk analysis. Risk for the full crop rotations in each system was assessed using the method of Musser et al.[31] in which a lower confidence limit for returns, L, is calculated as

$$L = E - KS,$$

where E is the average net return, K is the number of standard deviations required to satisfy the farmer that average returns in a given year will exceed L at a given level of probability and S is the standard deviation. We set the lower confidence limit at 75%, which means that average returns in three of four years will exceed L. For a normal distribution, $K = 0.674$ for a 75% lower confidence limit[17].

Statistical analyses. Analyses of variance for economic returns were conducted by year and crop with cropping system as a fixed effect and block as random effect using PROC MIXED in SAS, Version 9.1[32]. Analyses across years were conducted as above except with block and year as random effects.

Results and Discussion

Crop yields

Crop yields—especially those of corn and soybean—varied with year (Table 7), largely due to annual differences in rainfall[16]. For example, rainfall from May to August 2002 was 60% of the 30-year average (404 mm), while rainfall from May to July 2003 was 158% of the 30-year average (310 mm); crop yields were commensurately low during these years (Table 7). There were no differences in average grain yields between NT and CT, and average corn and soybean yields in these conventional systems were greater than in the three organic systems (Table 7). Among organic systems, average corn yield increased with increasing crop rotation length and diversity, being 41, 31 and 24% less than in CT (8.03 Mg ha^{-1}) in Org2, Org3 and Org4+, respectively[16] (Table 7). Soybean yield in the organic systems was, on average, 19% lower in the organic (average = 2.88 Mg ha^{-1}) than in the conventional (average = 3.57 Mg ha^{-1}) systems and there were no consistent differences in wheat yield among any systems (overall average, 2000 to 2002 = 4.09 Mg ha^{-1}; Table 7). There were no consistent impacts of crop rotation length and complexity among organic systems on soybean or wheat yields. A multiple regression analysis showed that nitrogen, weeds and plant population were associated with 73, 23 and 4%, respectively, of differences in corn yields between the CT and the organic systems, and weeds were associated with 100% of soybean yield differences between the CT and organic systems[16]. It is possible that different planting

Table 7. Grain yields for corn, full-season soybean and wheat harvested from cropping systems at the USDA–ARS Beltsville FSP, Beltsville, Maryland.[1] Org2, Org3, and Org4+ are, respectively, a 2-year, a 3-year, and a 4- to 6-year organic crop rotation.

		Grain yield[2] (Mg ha^{-1})						
Crop	**System**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**Mean[3]**
Corn	No-till	8.20 ab	7.75 a	3.81 a	4.30 b	12.5 a	10.3 ab	7.81 a
	Chisel till	9.09 a	7.81 a	3.36 a	5.59 a	11.7 a	10.6 a	8.03 a
	Org2	7.56 b	4.89 b	0.08 c	2.38 c	7.38 b	6.09 d	4.73 d
	Org3	7.81 b	4.82 b	0.55 b	3.16 c	8.08 b	8.89 c	5.55 c
	Org4+	8.12 b	7.95 a	0.98 b	2.71 c	8.33 b	8.72 bc	6.13 b
Soybean	No-till	–	4.31 a	1.75 a	4.05 a	4.03 a	4.35 a	3.70 a
	Chisel till	–	4.24 a	2.05 a	3.39 b	3.63 a	4.16 ab	3.49 a
	Org2	4.76 a	3.58 ab	0.68 c	2.38 c	3.54 a	3.72 bc	2.78 b
	Org3	4.91 a	3.28 b	0.87 c	2.98 b	3.74 a	3.37 c	2.85 b
	Org4+	4.78 a	3.09 b	1.27 b	2.95 b	3.66 a	4.04 ab	3.00 b
Wheat	No-till	3.29 a	4.63 b	4.03 c	–	–	5.04 a	3.98 a
	Chisel till	2.97 a	4.79 b	5.01 ab	–	–	5.00 a	4.26 a
	Org3	1.61 b	5.24 a	4.78 b	–	–	–	3.88 a
	Org4+	1.77 b	5.50 a	5.45 a	–	–	–	4.24 a

[1] From Cavigelli et al.[16].
[2] Values within crop and year followed by the same letter are not significantly different at $P < 0.05$.
[3] Means are for years when all five cropping systems were represented: for corn, 2000–2005; for soybean, 2001–2005; for wheat, 2000–2002.

dates and crop varieties in conventional and organic systems, which were not included in these analyses, might also have impacted these results.

Average crop yields in organic systems have been shown to equal those in conventional systems in Iowa (corn and soybean)[14,18], Pennsylvania (corn and soybean)[9,17,22,23,33], Minnesota (soybean but not corn)[15,24] and California (corn)[12]. Our results may have differed from these study results due to differences in soil fertility and weed control. For example, as noted by Delate et al., high organic crop yields in their study are predicated on adequate soil fertility[18]. In addition to the Mollisols in Iowa being inherently more fertile than the Ultisols on which our study was conducted, the Iowa researchers added compost containing a total of 135 kg N ha^{-1} each year prior to planting corn. We have shown that lower N inputs in our organic than in our conventional systems were associated with lower corn yields in the organic systems in part because we limited application of animal manures due to high soil P[16]. Delate and Cambardella[14] recognized that increasing soil P was a concern in their organic systems. Delate and Cambardella[14] also noted that weed control was very effective in their 4-year study. By contrast, weed control in our study was variable and was associated with 23 and 19% lower average corn and soybean yields, respectively, in organic than conventional systems[16].

Performance of conventional crops among studies also differed. For example, yields in our conventional systems were significantly greater than those in the Pennsylvania (Rodale) study. Conventional corn and soybean yields (7.04 and 2.50 Mg ha^{-1}, respectively) at Rodale for the years 1991 to 1995[22], when their organic legume systems were essentially identical to Org3 in our study, were lower than in our study by 12 and 28%, respectively. This difference is even more substantial when 2002, a year with extremely low yields in all systems due to very dry soil conditions, is not included in our results. In that case, conventional corn and soybean yields at Rodale were 21 and 34%, respectively, lower than conventional corn and soybean yields at FSP. When 2002 data are not included in the FSP means, average organic corn yields were similar between sites (6.84 and 6.55 Mg ha^{-1} for Rodale and FSP, respectively) and organic soybean yields at FSP were greater than at Rodale by 30%. Thus, differences in organic and conventional corn and soybean yields between these two sites reflect more strongly differences in conventional rather than organic crop yields.

Our results are more consistent with those from Minnesota in which corn yields were at least 34% lower in organic than in conventional systems[15,24]. As in the Minnesota study[15], weed pressure at our site was exacerbated in years when wet soil conditions in the spring precluded ideal timing of rotary hoeing or cultivation activities[16]. We believe differences in crop yields between organic and conventional systems in our study provide a good indication of expected organic and conventional crop yields in the Coastal Plains region of the mid-Atlantic region. They reflect regional constraints to organic grain crop production and the ability to produce high-yielding conventional crops. Constraints in the mid-Atlantic region include soils with less inherent N fertility and soil organic matter than, for example, Midwest Mollisols and high soil P that precludes regular, large additions of animal manures.

Crop yields among our organic systems followed a similar pattern as that reported by Mahoney et al.[19], who showed greater corn yield following alfalfa (in an organic

Table 8. Average production costs by crop for five cropping systems at the FSP, Beltsville, Maryland. Org2, Org3 and Org4+ are, respectively, a 2-year, a 3-year and a 4- to 6-year organic crop rotation.[1]

		Costs (US$ ha^{-1})					
Crop	System	Tillage	Machinery other than tillage	Seed, fertilizer	Pesticides	Manure	Total
Corn	No-till	0	265	296	136	0	697
	Chisel-till	131	262	292	97	0	782
	Org2	187	191	143	0	60	581
	Org3	269	215	187	0	37	709
	Org4+	207	186	117	0	55	564
Soybean, full-season	No-till	0	276	192	88	0	556
	Chisel-till	84	271	194	64	0	613
	Org2	157	208	163	0	0	528
	Org3	168	210	159	0	0	537
	Org4+	168	219	166	0	0	553
Wheat	No-till	0	334	95	39	0	468
	Chisel-till	103	316	95	19	0	533
	Org3	89	142	30	0	91	352
	Org4+	89	153	30	0	91	363
Soybean, double-cropped	No-till	0	142	115	53	0	310
	Chisel-till	0	153	98	53	0	304
Forage crops	Org4+	68	197	96	0	68	429

[1] Means are for years when all five cropping systems were represented: for corn, 2000–2005 (not including 2002, as described in text); for soybean, 2001–2005; for wheat, 2000–2002; for hay, 2000–2005.

4-year corn–soybean–oats/alfalfa–alfalfa rotation) than in a two-year organic corn–soybean rotation in a 10-year study. However, Archer et al.[15], in a 4-year study, found no differences in corn yield in similar 4- versus 2-year rotations, and Delate and Cambardella[14] found no differences in corn yields in a 3-year corn–soybean–oats/alfalfa versus a 4-year corn–soybean–oats/alfalfa–alfalfa rotation. One possible reason that Archer et al.[15] and Delate and Cambardella's[14] results differed from ours and those of Mahoney et al.[19] is that their shorter (4-year) studies included the first 2 or 3 years of an organic transition period, during which time rotation impacts may not be apparent yet.

Enterprise analysis

Production costs. Average total cost of production for each crop except double-cropped soybean was greater for CT than for all other cropping systems (Table 8). While pesticide costs (almost exclusively herbicides) were lower for CT than for NT, tillage costs for CT were substantial and resulted in total costs for CT that were 10–14% greater than in NT for corn, soybean and wheat. Average total cost of production for corn in NT was greater than for corn in Org2 and Org4+ by 20–24%, respectively, but less than for corn in Org3 by 2%. Costs of production were greater in Org3 than in Org2 largely because the cost of planting the vetch cover crop was greater in Org3 than in Org 2. Vetch was planted every year in Org3 but only in 3 of 6 years in Org 2 due to wet soil conditions after soybean harvest in October 2002, 2003 and 2004 (Table 2). Soils are much less likely to be too wet to plant for extended periods of time in late August or early September, when vetch was planted in Org3. Costs of production were greater in Org3 than in Org4+ because establishment costs for the perennial forage crop that preceded the corn crop in Org4+ were allocated to the forage portion of that rotation, while the cost of establishing the vetch cover crop was allocated to the corn in Org3 and Org2.

Average total cost of production for full-season soybean in the three organic systems was only 1–5% less than that for NT. Tillage costs in the organic systems were about equal to the difference in fertilizer, pesticide and application costs between NT and the organic systems. For wheat, average total production costs were 29–51% greater for conventional than for organic systems due to costs of purchasing and applying fertilizers and pesticides, and harvesting straw in the conventional systems. Cost of harvesting straw is reflected in machinery costs; costs of spreading and incorporating wheat straw in the organic systems are incorporated in wheat harvest and vetch seedbed preparation costs (Table 8).

Most other studies have also found that costs of production are usually lower in organic than in tilled conventional systems due to reduced fertilizer and pesticide materials and application costs[15,17–21]. However, our study seems to be the first to report costs of production for

Table 9. Present value of net returns for individual crops in five cropping systems at the FSP, Beltsville, Maryland, with and without price premiums for organic crops.

Crop	System	Present value of net returns (US$ ha^{-1})[1]												Cumulative[2]	
		2000		2001		2002		2003		2004		2005			
Corn							*Organic prices*								
	Org2	1056	A	216	B	−575	C	−123	BC	1017	AB	993	B	2584	C
	Org3	1117	A	69	C	−442	BC	−51	B	956	B	1694	A	3342	B
	Org4+	1169	A	916	A	−476	BC	97	A	1236	A	1722	A	4665	A
							Conventional prices								
	No-till	89 b	B	217 b	B	−171 a	A	−231 ab	C	180 a	C	9 a	C	94 a	D
	Chisel till	31 b	B	56 c	C	−346 b	B	−142 a	BC	110 ab	C	−16 a	C	−307 b	D
	Org2	240 a		−86 d		−584 c		−308 bc		−98 c		−240 c		−1078 c	
	Org3	274 a		−229 e		−496 c		−393 c		−265 d		−105 b		−1214 c	
	Org4+	293 a		424 a		−569 c		−196 ab		−23 bc		−43 ab		−114 ab	
Soybean, full-season							*Organic prices*								
	Org2	3184	A	1950	A	−94	C	576	B	1346	A	1347	AB	5125	A
	Org3	3208	A	1756	A	35	B	1172	A	1481	A	1175	B	5619	A
	Org4+	3135	A	1627	A	232	A	1122	A	1433	A	1541	A	5955	A
							Conventional prices								
	No-till	–		481 a	B	−226 a	D	499 a	BC	517 a	B	366 a	C	1637 a	B
	Chisel till	–		459 ab	B	−256 a	D	208 b	C	412 a	B	217 bc	C	1040 b	B
	Org2	753 a		376 abc		−365 a		−27 c		374 a		156 bc		514 c	
	Org3	700 a		315 bc		−312 a		162 b		455 a		97 c		717 bc	
	Org4+	695 a		270 c		−276 a		121 b		430 a		248 ab		793 bc	
Soybean, double-cropped							*Conventional prices*								
	No-till	363 a		−43 a		−52 b		–		–		203 a		471 a	
	Chisel till	318 a		−85 a		67 a		–		–		177 a		477 a	
Wheat							*Organic prices*								
	Org3	128	B	1220	A	871	B	–		–		–		2219	B
	Org4+	175	B	1297	A	1032	A	–		–		–		2504	A
							Conventional prices								
	No-till	375 a	A	663 a	B	496 a	C	–		–		562 a		1534 a	C
	Chisel till	221 b	B	593 a	B	559 a	C	–		–		437 b		1373 b	C
	Org3	−160 c		310 b		207 b		–		–		–		357 c	
	Org4+	−142 c		342 b		275 b		–		–		–		475 c	
Forage crops							*Conventional prices*								
	Org4+	24		609		943		−32		−36		104		1612	

[1] Results of means comparisons between conventional systems and organic systems when organic premiums are used to calculate returns for organic systems are indicated by upper case letters; when followed by the same upper case letter within a column for a given crop, means are not significantly different at $P < 0.05$; lower case letters are used in the same manner to compare results when no organic price premiums are used.

[2] Values are for years when all five cropping systems were represented: for corn, 2000–2005; for soybean, 2001–2005; for double-cropped soybean, 2000–2002 and 2005; for wheat, 2000–2002; for forage crops, 2000–2005.

organic systems compared to NT systems. While lower cost of production has been heralded as an advantage for organic production systems compared to conventional systems[18,22,33], our results show that this may not be the case when the conventional systems are NT, at least for corn and soybean. A lack of substantial difference in production costs between NT and organic systems may be a previously unidentified reason that farmers, especially those using NT practices, may not choose to adopt organic production practices.

Corn. With organic price premiums, present value of net returns for corn was substantially greater for Org2 and Org3 than for the two conventional systems in 3 of 6 years (2000, 2004 and 2005; Table 9). Returns for Org4+ were considerably greater than for the conventional systems in 5 of 6 years (all years except 2002 when corn and soybean yields were very low in Org4+) and were greater than for Org2 (2001, 2003 and 2005) and Org3 (2001, 2003 and 2004) in 3 of 6 years. Those years in which organic price premiums did not provide greater net returns for corn in organic than in conventional systems (Org2 and Org3 in 2001 and 2003, all organic systems in 2002) were years when corn grain yield was much lower than in conventional systems due

to limited nitrogen availability and/or weed competition in the organic systems[16]. In 2002 and 2003, respectively, the effects of these management challenges were exacerbated by the very dry and very wet weather previously mentioned. Returns for the period 2000 to 2005 were substantially greater for organic systems than for conventional systems and increased with increasing crop rotation length and diversity (Table 9). This pattern among organic systems reflects corn grain yields (Table 7) more strongly than it reflects production costs (Table 8).

Similar results are presented in one of the few economic analyses of organic production systems that includes an analysis of returns by individual crop. That study, conducted from 1999 to 2001 in Iowa, shows that returns for corn with organic price premiums were substantially greater than for conventional corn[18]. These authors, however, found no impact of crop rotation length between a 3-year and a 4-year rotation on returns for organic corn.

When conventional prices were used, present value of net returns for corn was among the highest for NT (2002–2005) and for Org4+ in 4 of 6 years (2000, 2001, 2003 and 2005; Table 9). Returns for Org4+ were equal to or greater than for NT in four of these years (2000, 2001, 2003 and 2005). Returns for Org2 and Org3 were among the lowest for all years except 2000 when yields in these two systems were 92 and 95%, respectively, of those in NT (Table 7).

With conventional prices, present value of net returns for corn was often negative in all five systems and cumulative returns for 2000 through 2005 were positive for NT only (Table 9). However, if 2002, a year that was not representative due to very poor yield in all systems, is removed from the analysis, cumulative present value of net returns are positive and not statistically different for Org4+ (US$456 ha^{-1}) and NT (US$265 ha^{-1}). Without the 2002 data, returns for CT (US$40 ha^{-1}) were less than for Org4+ and NT but substantially greater than for Org2 and Org3 (−US$494 and −US$718 ha^{-1}, respectively). Returns for Org4+ were similar to those for NT because lower yields (Table 7) were balanced by lower production costs for Org4+ compared to NT (Table 8). Greater net returns for NT than CT reflected lower production costs in NT (Table 8) rather than differences in yield (Table 7). On the other hand, lower returns for Org2 and Org3 than for the conventional systems were due to lower yields (Table 7) rather than to large differences in production costs (Table 8).

The average price for organic corn was 118% greater than for conventional corn during the period 2000 to 2005 (Table 6). Returns for corn would have been equal to those for NT at average organic price premiums of 38, 39 and 6% for Org2, Org3 and Org4+, respectively. Returns would have been equal to those for CT at average organic premiums of 24 and 27%, respectively, for Org2 and Org3.

Soybean. When organic price premiums were used, net returns for full-season soybean were greater for the three organic systems than for the two conventional systems every year except 2003 (Table 9) when returns for Org2 were not different than for NT. Soybean yield in Org2 was ~80% of that in Org3 and Org4+ that year (Table 7) due to poor weed control[16]. Net returns for Org4+ were greater than for Org2 (2002 and 2003) and Org3 (2002 and 2005) in 2 of 5 years and net returns for Org3 were greater than for Org2 in 2003 only; there were no other differences in net returns among the organic systems. Cumulative present value of net returns for 2001 through 2005 was not different among the three organic systems (US$5566 on average) and was greater than in the NT system by a factor of 3.4 on average and greater than in the CT system by a factor of 5.4 on average (Table 9). Soybean analyses do not include the year 2000 because there were no full-season soybeans in NT and CT that year, as described previously.

The Iowa study that includes an economic analysis of returns by individual crop shows similar results for soybean as for corn: returns for soybean with organic price premiums were substantially greater than for conventional soybean but there was no impact of a 3-year versus a 4-year rotation on returns for organic soybean[18].

With conventional prices, full-season soybean was a profitable crop in most systems all years, except for 2002 when low yields (Table 7) resulted in negative returns for soybean in all systems (Table 9). In 2 of the 5 years when full-season soybean was present in all five systems (2002 and 2004) there were no statistical differences in net returns among the five systems. In the other 3 years, returns were among the greatest for NT and CT. There were no consistent patterns among the three organic systems but in the 3 years when there were differences among organic systems (2001, 2003 and 2005), returns for Org3 were no different than those for CT, while returns for Org 2 were lower than for CT only in 2003 and returns for Org4+ were lower than for CT only in 2001.

Cumulative present value of net returns for the years 2001 to 2005, when full-season soybean was present in all systems, was 57% greater for NT than for CT, which, in turn, was 102% greater than for Org2 but not greater than for Org3 and Org4+ (Table 9). Net returns for soybean were greater for NT than for CT as a result of lower production costs in NT (Table 8) and not to differences in yield (Table 7). Lower net returns in the organic systems compared to NT were due to lower yields (Table 7) rather than to any substantial differences in production costs (Table 8). The pattern of net returns between CT and the organic systems was affected by differences in both yields and costs of production (Tables 7 and 8). There were no differences in cumulative net returns among the three organic systems, reflecting similar average soybean yield and production costs among these three systems.

During the time period 2001 to 2005, the average price for organic soybean was 138% greater than for conventional soybean (Table 6). Returns for soybean would have been equal to those for NT at average organic price

premiums of 33, 25 and 22% for Org2, Org3 and Org4+, respectively. Returns for soybean would have been equal to those for CT at average organic price premiums of 15, 9 and 6% for Org2, Org3 and Org4+, respectively.

There were few differences in net returns for double-cropped soybean between NT and CT (Table 9). Returns were positive in 3 of 4 years for CT (2000, 2002 and 2005) and 2 of 4 years for NT (2000 and 2005). Returns for double-cropped soybean were lower than those for full-season soybean in those years when both were grown (present value of net returns for NT and CT combined, for full-season soybean = US$521 ha^{-1}; for double-cropped soybean = US$474 ha^{-1}); while yield was generally lower[16], costs of production were also considerably lower for double-cropped than for full-season soybean (Table 8).

Wheat. When organic price premiums were included for organically grown wheat, returns were greater for the two organic systems than for the two conventional systems in 2 of 3 years (2001 and 2002; Table 9) even though wheat straw sales were included in the returns for CT and NT but not for the organic systems. In 2000, returns for the organic systems were lower than for NT and similar to that for CT even with organic premiums. These differences were due to lower yields in the organic than the conventional systems but, more importantly, to not selling the wheat straw produced in the organic systems. Cumulative returns for the years 2000 to 2002 were greatest in Org4+, followed by Org3, then NT, then CT.

We know of no other US or Canadian studies that compare returns for a small grain crop between organic and conventional systems. The only other study with which we are familiar that included individual crop data for small grains in organic systems found no difference in returns for oats in a 3-year versus a 4-year rotation[18].

When conventional prices were used, present value of net returns for wheat for the years 2000 to 2002 and 2005 (wet weather in fall 2002 and 2003 precluded planting wheat that would have been harvested in 2003 and 2004, respectively) was greater for NT than for CT in 2 of 4 years (2000 and 2005) and cumulative return was greater for NT than for CT (Table 9). These results reflect lower production costs for NT than for CT (Table 8) rather than differences in yield (Table 7). Net returns for NT and CT were always greater than for Org3 and Org4+ even though production costs were significantly lower in the organic than in the conventional systems (Table 8). This was because wheat straw accounted for 68 and 78% of returns in NT and CT, respectively. While wheat grain prices were low during this time, Maryland had (and continues to have) strong markets for straw in the construction, residential and horse industries. Returns for wheat grain alone for the years 2000 to 2002 were US$519 and 302 ha^{-1} for NT and CT, respectively, indicating that the sale of straw has a much larger impact on returns from wheat than does production practice. Incorporating wheat straw into soil—which can contribute significantly to soil carbon[34] and conserve soil nutrients, especially potassium—is a common, although not ubiquitous, practice among organic farmers in the mid-Atlantic region (personal communication, N. Maravell and E. Fry, Maryland organic farmers). There were no differences in net returns for wheat between the two organic systems.

For this time period, the average price for organic wheat was 110% greater than for conventional wheat (Table 6). Returns for organic wheat would have been equal to those for NT at an average organic premium of 75 and 61% for Org3 and Org4+, respectively. Returns for organic wheat would have been equal to those for CT at an average organic premium of 60 and 49% for Org3 and Org4+, respectively. If straw sales are not included in returns for wheat, returns for organic wheat would have been equal to those for NT at an average organic premium of 10 and 2% for Org3 and Org4+, respectively, and both organic systems would have greater net returns than wheat in CT.

Forage crops. Red clover plus orchard grass (2000 and 2001) and alfalfa (2001–2005) were profitable enterprises in 4 of 6 years in Org4+ (2000–2002 and 2005). Returns in 2003 and 2004 were negative because the alfalfa died in all plots during 2003 due to extremely wet weather. Yield in 2003 and 2004 was therefore low and establishment costs, which were allocated to 2004 returns, were higher than usual as all plots, regardless of stand age, had to be replanted (Table 2). Net returns for forage crops were US$1612 ha^{-1} for the period 2000 through 2005, US$1588 ha^{-1} for the period 2001 through 2005, and US$1576 ha^{-1} for the period 2000 through 2001, all of which are much greater than returns for corn, soybean and wheat, respectively, grown in the organic systems during the same periods and when no organic premiums were included (Table 9). Returns for forage crops were also greater than for corn in NT and CT. These results are consistent with other data from Maryland that show that forage crops are significantly more profitable than conventional corn[35]. However, when organic premiums are obtained for corn, soybean and wheat net returns for these crops are much greater than that for forage crops (Table 9). We know of no other studies that have presented economic returns for the forage portion of organic rotations independent of results for the full rotation.

Full rotations. When organic price premiums are used in the analysis, annual returns were greater for all organic systems than for all conventional systems during years with normal rainfall (2000, 2001, 2004 and 2005; Table 10). The only exception is Org4+ in 2004, which had poor returns for alfalfa (Table 9), and in which no wheat had been planted the previous fall, two changes dictated by wet soil conditions. In part because of inconsistencies in crop rotations due to extreme weather conditions, there were no consistent patterns in net returns among the organic systems during the 6-year study period, 2000 to 2005. For example, in 2002, when rainfall from May to September was 60% of the 30-year average, corn and soybean yields were very low in all organic

Table 10. Present value of net returns for five cropping systems at the FSP, Beltsville, Maryland, with and without price premiums for organic crops.

	Present value of net returns (US$ ha^{-1})[1]							
System	2000	2001	2002	2003	2004	2005	Cumulative 2000–2005	Cumulative 2000–2002
				Organic prices				
Org2	2120 A	1083 A	−334 D	226 BC	1182 A	1170 A	5446 A	2869 A
Org3	1484 B	1015 A	154 B	374 A	812 B	956 B	4796 B	2653 B
Org4+	910 C	1046 A	760 A	182 BC	421 C	613 C	3933 C	2717 AB
				Conventional prices				
No-till	413 a D	439 b B	16 b BC	256 a AB	405 a C	380 a D	1909 a D	869 b C
Chisel till	285 b E	341 c B	8 b C	91 b C	312 b C	272 b D	1309 b E	634 c D
Org2	497 a	145 d	−475 d	−167 d	138 c	−42 d	94 c	167 d
Org3	271 bc	132 d	−200 c	−77 cd	63 cd	−3 d	187 c	203 d
Org4+	184 c	579 a	534 a	−34 c	44 d	104 c	1411 b	1296 a

[1] Results of means comparisons between conventional systems and organic systems when organic premiums are used to calculate returns for organic systems are indicated by upper case letters; when followed by the same upper case letter within a column, means are not significantly different at $P < 0.05$; lower case letters are used in the same manner to compare results when no organic price premiums are used.

systems (Table 7) and returns were inversely proportional to the frequency of these summer annual crops in the rotation, i.e., returns were greatest in Org4+ and least in Org2. Conversely, in 2000, 2004 and 2005 returns for Org2 were greater than for Org3 and Org4+ because forage crops had low returns (2000 and 2004) due to high establishment costs and/or wheat was absent (2004 and 2005) due to weather conditions.

Cumulative present values with organic premiums were substantially greater for all three organic systems than for the conventional systems (Table 10). During the full study period, 2000 to 2005, net present value was greatest for Org2, which included a high revenue-producing soybean crop in half of all subplots each year and which did not include any fall-planted cash crops. Lower net present values for Org3 and Org4+ than for Org2 during this time period reflect the lack of complete rotations (no wheat from 2003 to 2005, and loss of alfalfa in 2003) in these systems during 3 of these 6 years (Table 2). While the incomplete rotations reduce our ability to compare full rotations for the entire 6-year study period, these inconsistencies likely reflect challenges that farmers with similar rotations might also face. Despite these challenges, cumulative present value for Org4+, which had the lowest returns among the organic systems, was approximately double that for NT, the conventional system with the greatest present value.

The period 2000 to 2002 covers years when all cropping phases of all organic rotations were present and avoids the years when alfalfa died due to wet weather (2003) and wheat was not present (2003–2005) because it was not planted the previous fall due to wet soil conditions. From 2000 to 2002, cumulative net returns for Org2 were greater than for Org3 by 8%, while those for Org4+ were not statistically different than for Org2 or Org3. Cumulative net returns for the three organic systems were greater than for the conventional systems by a factor of 3–4.5 (Table 10).

Our results are similar to a number of other studies that show net returns for organic systems being substantially greater than for conventional systems when organic price premiums are included in the analysis[15,18,19,21,23,24]. Two of these studies showed that returns for organic systems would be greater than for conventional systems even when price premiums were set at 50% of existing premiums at the time of the analyses[19,24]. Our results are also consistent with these results in that we showed that returns for organic crops would equal those for conventional crops with organic premiums that are 5–33% of existing premiums for corn, 4–24% of existing premiums for soybean, and 0–9% of existing premiums for wheat. Our results, however, indicate that organic premiums are necessary for organic systems to compete with conventional systems in the mid-Atlantic region, in part because yield potential in conventional systems in our region seems to be greater than, for example, in Pennsylvania, as discussed earlier.

Costs of production may also differ regionally. Other studies have highlighted two important costs of production that can vary considerably and which can influence the outcome of economic analyses: labor[18,22] and manure transportation and materials costs[15,18,20,24]. Since labor costs are generally recognized as being higher, albeit distributed more evenly across time, in organic than conventional systems, changes in labor costs tend to have a larger impact on economic returns in organic than in conventional systems[18,22]. Labor costs in our analysis were relevant to our region as they were incorporated in the Maryland custom rates used for each farming operation. Given the current uncertain global economic situation, the importance of labor costs will need to be given close scrutiny in future analyses.

Table 11. Mean annual net returns[1], standard deviation of net returns, and 75% lower confidence limit of net returns for five cropping systems at the FSP, Beltsville, Maryland, for two time periods, with and without price premiums for organic systems.

	Net returns (US$ ha^{-1})					
	2000–2005			2000–2002		
System	Mean[2]	Standard deviation	Lower limit	Mean[2]	Standard deviation	Lower limit
			Organic prices			
Org2	775 A	689	310	721 A	940	87
Org3	683 B	376	429	681 A	501	343
Org4+	554 C	237	394	716 A	100	648
			Conventional prices			
No-till	277 a D	141	181	223 b B	183	100
Chisel till	190 b E	118	110	163 c C	139	70
Org2	4 c	265	−174	29 d	392	−235
Org3	21 c	131	−67	46 d	192	−83
Org4+	193 b	209	52	348 a	182	225

[1] Summary values of net returns over variable costs are computed from values in Table 9.
[2] Results of means comparisons between conventional systems and organic systems when organic premiums are used to calculate returns for organic systems are indicated by upper case letters; when followed by the same upper case letter within a column, means are not significantly different at $P < 0.05$; lower case letters are used in the same manner to compare results when no organic price premiums are used.

A number of authors emphasize the importance of obtaining manures and composts on-farm or from nearby locations because transportation costs can make manure or compost cost-prohibitive[15,18,20,24]. For example, Delate et al.[18] showed that returns for both 3- and 4-year organic rotations were lower than for a conventional corn–soybean rotation when a compost cost of US$18 Mg^{-1} is included in the analysis. When the cost of the compost was set at US$0 Mg^{-1}, which assumes that the compost is produced on-farm, returns were significantly greater in the two organic systems than in the conventional system. We used a cost of manure in our study of US$11 Mg^{-1}, which assumed a source near our plots. However, it should be noted that sourcing manure in the mid-Atlantic region has become more challenging since 2005 (personal communication, D. Shirley and J. Spargo, USDA-ARS) since demand for animal manures tends to track the price of fertilizers, which have increased since then.

When conventional pricing was used, present value of net returns for the full rotations was greatest for NT in 4 of 6 years (2000 and 2003–2005) and for Org4+ in the other 2 years (Table 10). Net returns for CT were less than for NT all years except 2002, greater than for Org2 and Org3 all years except 2000, and greater than for Org4+ all years except 2001 and 2002. Years with low returns for Org4+ (2000, 2003 and 2004) were years when returns for the forage crops were low (Table 9) due to high production costs and/or poor yields (data not shown). Cumulative present value over the full study period, 2000 to 2005, was, on average, 40% greater for NT than for Org4+ and CT (Table 10). For the 2000 to 2002 period, the years when all crops were present in all organic systems, cumulative present value for Org4+ was 49% greater than for NT and 104% greater than for CT (Table 10). Cumulative present value for Org2 and Org3 was substantially lower than for the other systems during both study periods.

Our results are consistent with those for the Rodale site for the years 1991 to 1995, when their organic legume system was essentially identical to our Org3 system[22]. During this time period, returns without organic premiums were lower for the organic than for a conventional, tilled system, even though crop yields in the conventional system were lower than in our study.

To explore the economic risk associated with each rotation, mean annual returns, standard deviation and lower confidence limits for the full rotations are presented across the two different time periods: 2000 to 2002, when all crops were present in all organic rotations and 2000 to 2005, which includes years when full rotations were not always present in all systems (Table 10). When organic price premiums were included, mean net returns were either inversely related to the length and complexity of the rotation (2000–2005) or equal among the three organic rotations (2000–2002). This result suggests that growing only crops for which there are significant organic premiums rather than soil building crops (forage crops, which did not receive an organic premium in our study, and wheat) may offer economic advantages in the short term. However, Org2 also had the highest variability of returns and highest risk among organic systems with price premiums (a smaller lower limit represents a greater risk; Table 11).

When the 2000 to 2002 timeframe was used, there was a strong negative relationship between risk and the length and diversity of the crop rotation. The lower limits for Org3 and Org4+ were 3.9 and 7.4 times greater, respectively, than for Org2. Despite differences in relative economic

performance for the three organic systems based on the study period selected, the three organic systems substantially outperformed the two conventional systems in net returns when organic price premiums were included: on average, net returns for organic systems were 2.4–3.2 and 3.5–4.3 times greater than those for NT and CT, respectively. Except for Org2 during the time period 2000 to 2002, risk for the organic systems was always at least 1.7 and 2.8 times lower than for NT and CT, respectively.

With conventional pricing, NT had greater mean annual returns and lower risk than CT (Table 11). As for individual crops, these differences were due to typically lower production costs for NT than for CT, while yields were similar for the two systems. When all years were included in the analysis and conventional prices were used, returns were greater and risk was lower for NT than for all other systems. However, when only years with complete organic rotations, 2000 to 2002, were used, Org4+ had the greatest returns and lowest risk, indicating that incorporating a forage crop into a grain rotation can increase returns and lower risk when all crops are managed organically and no price premiums are obtained. Mahoney et al.[19] reached a similar conclusion in southern Minnesota. Alternatively, results from the 2000 to 2005 period indicate that including alfalfa in the rotation can add a level of risk that is realized in an extremely wet year such as 2003 when alfalfa died. In either case, without organic premiums, returns were substantially greater and risks were substantially lower for Org4+ than for Org2 and Org3, indicating there was a positive relationship between crop rotation length and complexity among the three organic systems when no organic premiums were received.

Our results probably explain why short crop rotations similar to Org2 have been adopted by a number of organic farmers in the mid-Atlantic region, especially those who have recently converted to organic systems (personal communication, L. Howard, Maryland organic farmer; C. Lawrence, Natural Resources Conservation Service, Virginia), i.e., these systems can have higher short-term returns than longer rotations. These systems may also be easier to manage, at least in the short term, because they include crops with which area farmers have previous experience[8]. Short crop rotations that include only summer annual crops, however, can result in increased weed populations[36] and, as we have shown here, result in greater economic risk. The fact that many established, mid-Atlantic organic grain farmers include perennial forage crops in their rotations suggests they understand these long-term consequences of relying on short-term crop rotations (personal communication, N. Maravell and E. Fry).

Conclusions

Our results show that when organic price premiums are included, net returns were at least 2.4 times greater and risk was at least 1.7 times lower for organic systems (except for Org2) than for conventional systems under the conditions described over this study period (2000–2005) in Maryland. It is important to note that these results occurred despite greater management challenges in the organic systems than in the conventional systems: wheat was not planted for 3 years in the organic systems due to wet fall weather (and 2 years in the conventional systems for the same reason), alfalfa died in Org4+ in 2003 and had to be replanted, and weed control was often less than optimal in the organic systems as wet weather in the spring limited our ability to rotary hoe or cultivate in a timely manner in some years.

Over the full 6-year study period, 2000 to 2005, when organic systems received price premiums, Org2 had the greatest net present value and greatest mean returns but also had the greatest variability of returns and greatest risk among organic systems. With organic premiums, Org4+ had the lowest variability of returns and Org3 or Org4+, depending on the time period used, had the lowest risk. For the period 2000 to 2002, the years when all crops were present in all organic systems, mean annual returns and net present value were similar among organic rotations but variability and risk were lowest with Org4+. The Org4+ system thus appears to be a good choice for farmers with management resources to carry out the extended rotation.

On a crop-by-crop basis, economic differences were also noted. Among the organic systems, returns for corn increased with increasing crop rotation length and diversity, reflecting yield patterns and lower production costs for Org4+ than for Org3. Returns for wheat also increased with increasing crop rotation length and diversity. However, returns for soybean, which had the greatest net present value of any of the crops when organic premiums were included, did not vary with crop rotation length and diversity. Because soybean had the greatest returns, Org2, which had soybean in the rotation most frequently, had the greatest returns among organic rotations during the study period. This likely explains why a number of organic grain farmers in the mid-Atlantic region are using these shorter rotations, which include a high proportion of high-revenue crops relative to soil-conserving crops such as winter wheat and perennial forage crops.

It is important to note that there are often marketing and post-harvest costs and risks associated with obtaining organic price premiums that are not accounted for in this analysis. These costs include time involved in certifying a farm, identifying, contacting and developing a relationship with grain buyers, and drawing up contracts. Risks include an insurance system that is less well developed for the organic than for conventional markets, and inherent risks involved with emerging markets in general[8]. Our analysis shows that marketing and post-harvest costs might easily be captured and that greater risks could be justified with current price premiums since organic crops would have been as profitable as conventional crops with price premiums for corn (2000–2005), soybean (2001–2005) and wheat (2000–2002) that were 5–32%, 4–24% and 45–68%, respectively, of premium prices averaged over the course of the study (2000–2005). These results also indicate that

organic systems could be competitive with conventional systems even if price premiums decrease—to a point—in response to increasing production relative to demand. Our results also show that including a forage crop in a grain production system reduces economic risk, improves revenue, and can make economic returns from an organic rotation competitive with conventionally grown rotations even, in some years, when price premiums are not obtained. Managing a forage crop, however, requires specialized equipment and identifying a market, the full costs of which are not included in this analysis.

While grain prices, both organic and conventional, have fluctuated considerably since 2005, organic price premiums, as of March 2009, for organic feed grains remain similar—117% for corn (compared to 118% from 2000 to 2005), 123% for soybean (compared to 138% from 2001 to 2005)—or somewhat lower—53% for wheat (compared to 111% from 2000 to 2002)—than those reported for the period 2000 to 2005 in this study[2–5]. Thus, we believe that the general conclusions derived from this study comparing economic returns between organic and conventional systems are likely to be valid in the current economic situation.

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Renewable Agriculture and Food Systems: 24(2); 120–136 doi:10.1017/S1742170509002531

Ten percent organic within 15 years: Policy and program initiatives to advance organic food and farming in Ontario, Canada†

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Accepted 20 February 2009 **Research Paper**

Abstract

With growth in retail sales estimated by industry at 15–25% yr^{-1}, organic food represents the only significant growth sector in Canada's food system. This reality, in combination with mounting evidence that substantial environmental and economic benefits can arise from organic farming adoption, suggests that organic sector development should be a priority for governments. However, organic food remains a marginal component of Canadian agricultural and trade policy. This study was designed to examine the opportunities and costs to the province of Ontario of strategic investment in the expansion of the organic sector. Drawing on existing literature and Ontario land use and production data, the study used an iterative process to identify how the province could reach a target of 10% of Ontario's cropped acres in organic production within 15 years, from the current level of about 1%. We concluded that after 15 years 5343 organic farmers would be producing organically in all major commodities, including 4254 converting farmers entering the organic sector and 600 new entrants to farming. The 489 organic farms reported in 2004 would be included in this total of 5343 because we assume that they all make modest additions over this time period to their existing operations. Organic production would occur on about 367,000 ha of land, and some 1.4 million animals would be reared organically. After 15 years, these farmers would reduce fertilizer applications by about 43 million kg (saving \$18.4 million yr^{-1}), pesticide applications by about 296,000 kg active ingredient (saving \$9.1 million yr^{-1}), and 7079 kg of growth-promoting antibiotics/medications consumed in animal feed. This 30-point program would require new investments by the provincial government of about \$51 million over 15 years. Phase I (first 5 years) costs would total \$7.1 million and Phase II (following 10 years) costs \$43.9 million. Net program costs would be significantly lower since farmers would have directly saved on inputs and received premium organic prices for most of their goods sold, thereby reducing government costs related to supporting farm finances. Additionally, this program would contribute significantly to reducing the externalized costs of current approaches to agriculture, conservatively estimated at \$145 million annually or \$2.18 billion over the 15-year life of the program. Not all those costs would be saved within 15 years, but this exceedingly modest investment in organic production, representing only 2.3% of these externalized costs, would generate savings in externalized costs far beyond this one-time investment. Implementation of this plan would allow domestic producers to capture 51% of Ontario's organic consumption, up from the currently low-range estimate of 15%. Organic foods would represent 1.9% of the total food retail market after 5 years and 5.3% of the total market after 15 years.

Key words: organic agriculture, transition, targets, Canada, Ontario, policy, programs, externalized costs, local food, import substitution

Introduction

The Canadian food and agriculture sector is facing some significant environmental, food safety and financial difficulties. These difficulties are affecting the market's

†A longer unpublished version of this paper appeared as MacRae, R., Juhasz, M, Langer, J. and Martin, R.C. 2006. Ontario Goes Organic: How to Access Canada's Growing Billion Dollar Market for Organic Food. World Wildlife Fund Canada (WWF-Canada) and the Organic Agriculture Centre of Canada, Truro, NS. http://www.organicagcentre.ca/ResearchDatabase/res_oos_intro.asp

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perceptions of Canadian food, both domestically and internationally. These realities explain, in part, the development of the 2002 Agricultural Policy Framework (APF), implemented in 2003–2008 by the federal, provincial and territorial governments, and the agreement to create a next generation of APF programs (or APF2).

Despite these preoccupations, with the possible exception of Quebec, Canadian governments have treated organic food and farming as a niche market, with very limited attention given to it in the new suite of APF programs. In many parts of the world, organic farming has been similarly promoted, but rapid growth rates this past decade suggest that providing policy supports on a niche market basis is misplaced. In several European countries, the organic sector has reached 10% of the agri-food economy and/or production area[1]. At such levels, it is estimated that some of the proposed benefits of organic farming[2,3] could be realized.

With growth in retail sales estimated at 15–25% yr^{-1}, organic food represents the only significant growth sector in Canada's food system[4]. This explains, in part, the recent spate of organic firm acquisitions by conventional food companies[5]. However, only 15–40% of the organic food consumed in Canada is produced domestically[4,6]. The rest is imported, primarily from the United States (perhaps 70–75%) and Europe[6]. In contrast, 70% of conventional foods consumed domestically are produced in Canada[7]. Consequently, Canadian farmers are missing out on many of the market opportunities that organic demand presents, at a time when net farm income in aggregate has been low[7]. Without domestic production to match demand, the significant environmental, health, financial and social benefits that can be associated with organic food production, processing and distribution are accruing elsewhere. Global trade in organic food is also contributing to greenhouse gas (GHG) emissions, causing many in the sector to question an export/import-oriented organic agricultural strategy and to call for a new post-organic or 'beyond organics' approach[8,9]. At the leading edge of this opposition to global organic is the UK Soil Association, which has suggested in a discussion paper that air-freighted organic may not in future be eligible for certification[10].

Market demand, on its own, appears to be insufficient to rapidly attract new Canadian organic producers and processors. It appears that even the presence of significant price premiums is insufficient to overcome the anxieties about and real challenges of the transition to organic production. European evidence suggests that only with supportive government interventions will the supply of organic foods increase relatively rapidly[11].

Government involvement is justified for many reasons consistent with historical interventions in the food and agricultural economy. Organic agriculture is an immature industry and governments have supported infant agricultural industries in the past, in Canada notably the canola oil industry on the Prairies and the wine sector in Ontario. These government investments in the organic sector progressively correct market failures—the fact that current approaches to production, processing and distribution do not reflect real costs, generating significant externalized costs the private landowners, the general public and governments have to pay for later. In theory, as the social and environmental benefits grow with organic farming adoption, government liabilities for these unfunded externalized costs should decline[12,13].

In earlier work (2002), the Canadian organic sector established a series of targets for growth, setting out some of the governmental and sectoral interventions considered necessary to expand organic food and farming[14]. This study was designed to further that analysis, focusing specifically on governmental and sectoral initiatives for the province of Ontario. Ontario was chosen for several reasons:

1. One of the most concentrated areas of market demand for organic products in Canada is the Greater Toronto Area (GTA)[4] and therefore Ontario farmers are well placed to meet this local market.
2. Production remains very limited, despite significant demand for a wide range of organic foods. In 2004 (the most up to date information at the time of the study), Ontario only had about 489 certified organic producers covering about 24,000 ha of cropland. Farm gate receipts were estimated at over $25 million. Certified organic processors only numbered in the hundreds[6]. Data from 2005 showed very small increases from 2004[15].
3. Although organic farming and processing data are generally weak in Canada, Ontario data are relatively better than many other provinces.
4. There is interest in organic agriculture at a political level. The Ontario government in the 2003–2007 period relied to some degree on external organizations to put forward detailed action plans that they might implement. Senior politicians expressed interest in seeing detailed ideas on advancing organic agriculture, as part of their consultations with the agricultural sector.

Since some countries in Europe have the most advanced organic sectors, the European experience developing the organic sector reveals key instruments that have been critical to success[11]. Most of the countries with significant development have used a mixture of supply-side and demand-side policies and programs, including:

1. Definitions of organic agriculture.
2. A uniform national (and for Europe an EU level) standard, with political recognition of standards, certification and accreditation. In the EU, there have been statistically positive impacts from introduction of the EU standard.
3. Financial support for transitional growers. Numerous studies show initial positive impacts from direct payments in the agri-environmental schemes; however, modifications to the schemes in the more mature countries like Denmark and Austria appear to have accelerated existing organic farming growth, but not necessarily brought in significant numbers of new organic farmers.

4. Advisory services and training to support the adoption process.
5. Local institutional supports for organic farming.
6. Supports for the development of organic markets—supermarkets and institutional buyers are often drivers of demand in Europe.
7. Coordinating and advising institutions to advance organics with positive participation and interaction with the conventional farming sector.

The European experience has led many states to recognize the need for a more integrated and balanced mix of policy and program measures[16]. This has produced a number of national action plans (and an EU plan) with both supply (push) and demand (pull) instruments with proposals for coordinating and implementation bodies. Denmark was the first to develop a plan (1995) and now England, Finland, France, Germany, the Netherlands, Norway, Sweden, Wales and Spain have plans. The plan rationales are to increase the size of the organic sector because of the public benefits that result. They normally include targets for adoption (typically 5–10% by 2000/2005 or 10–20% by 2010), direct financial support through the agri-environment/rural development programs; marketing and processing support; producer information initiatives; consumer education and infrastructure support. A typical mix is 50% of expenditures for direct payments and 50% for a host of other infrastructure- and training-related supports. Some plans focus more on demand-side interventions (e.g., the Netherlands), others on building information support systems for all players in the organic food chain (Germany) and others on increasing supply (England and Wales). Interestingly, almost all plans focus on the need for integrated farming systems and cooperation among all players in the food chain, and for formal advisory bodies that guide government decision-making on organic agriculture. Plans generally commit millions of dollars in public funds to implementation.

Among Canadian jurisdictions, only Quebec has a full strategic plan that rivals plans in Europe. A comparison of Quebec and European plans can be found at http://www.oacc.info/DOCs/Paper_Supports_Version2_rm.pdf.

The hypothesis of the present paper is that an Ontario plan can be designed and delivered that takes lessons from plans in other jurisdictions and adapts them to the Ontario environment, to accelerate the adoption of organic farming and food processing, and to reap the associated benefits for Ontario farmers and consumers.

Methods

Working from targets set out in the National Organic Strategic Plan (NOSP)[14] for adoption of organic farming and processing in different commodity areas, the study used an iterative process of analysis to identify specific and reasonable conversion targets in multiple commodity areas. Consistent with the NOSP, an overall target of 10% of cropped area was chosen but a wider range of targets was considered for individual commodities (see Table 4 for the list of commodities) in order to meet the overall target. Target setting allowed for estimates of the required number of new entrants to farming and conventional producers converting to organic. Programs and program initiatives were proposed to help meet those targets, based on successes elsewhere and expert opinion, and estimates of expenditures developed including the costs of a transition payments program that included payments for environmental services. Based on adoption targets, potential savings were identified in fertilizer, pesticide and antibiotic use associated with those transition targets.

Setting targets

The analysis determined:

- the number of hectares to be converted to organic production;
- crop by crop contributions to the overall 10% organic production target;
- the number of animal head to be converted;
- an estimate of the overall number of farms to be converted and new entrants to farming.

Crops were chosen based on data available on organic production (primarily production years 2003 and 2004). Specialty crops, such as ornamentals, herbs, bird seeds and ginseng, were excluded from the analysis because of insufficient data. Data on organic wheat, corn and hay/pasture had to be disaggregated, based on conventional ratios and expert information[17]. Organic vegetable production data were limited, so all vegetables had to be reported together, except potatoes. The fruit production analysis was based on availability of organic production data.

Animals were chosen based on data available on organic production. Specialty, smaller volume animal production and aquaculture were excluded from the analysis because of insufficient data. Conventional crop and animal production data were taken from 2004 Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) statistics[18], unless otherwise noted in our earlier report.

To establish 5 and 15 year targets for Ontario, we started from the national targets set out in the NOSP[14]. These were modified to reflect Ontario conventional and organic production realities and to balance crop and animal production requirements. Target hectares and head were calculated by multiplying conventional hectares (or animal head) by the target percentage for organic conversion. Current data on organic production, organic head and current organic farms were based on 2003 data provided by Macey[6] unless updated with 2004 data provided by Macey[19]. Area (and head) to be converted was calculated by subtracting current organic area (head) from 15-year target area (head). To estimate how many farms would be required to convert to a specific commodity production, we estimate the current size of an average organic operation. Where that information was not available, we used

conventional averages. We also took account of the size dispersal of operations in conventional production, under the assumption that most converting operations would not be in the largest size classes. Estimated additional numbers of farms reporting conversion to that crop (animal) were calculated by dividing area (head) to convert by the average size of an operation.

The average number of new organic farming entrants was estimated from conventional entrants. In the 1996–2001 period, 50,000 new farms entered[20], most existing farms under new management. In an average year, then, 10,000 new operations started up. Assuming an even distribution according to provincial farm ratios, then 24% of those entered in Ontario, meaning 2400 new farms annually. Assuming that 1% annually of those new entrants are organic, then 24 new farms yr^{-1} entered or 120 new farm entrants over a 5-year period. In Phase II, with a fuller suite of supports in place, we anticipated a doubling of new entrants to organic farming or 48 farms yr^{-1}. This would total 480 farms over 10 years, for a 15-year total of 600.

Since many operations are diversified, the farm totals for each commodity will not reflect accurately the total number of farms required for conversion. To estimate that, we found that in the 2001 Census of Agriculture, when adding up farms reporting crops in each commodity studied and comparing that to the total number of farms, the ratio was 2.5. In other words, each farm reported on average 2.5 of the studied crops. We assumed the number would be higher in organic production, since these operations are usually more diversified, so we divided the total of all farms required by three to come up with our estimate. We did not add in animal production numbers since we assumed that all organic livestock operations would also report crops.

As a check on the merits of our preliminary targets, we also examined rotation patterns and feed requirements for cattle (assuming primarily forage-based diets) and adjusted our targets accordingly. Given the relatively low rates of non-ruminant conversions, we did not anticipate any problems ensuring sufficient feed grain availability, although current shortages are acute in some regions and often a product of price differentials between human and animal feed markets.

One weakness of this analysis is that we were unable to account for dynamic changes in crop rotations, in part because Ontario does not collect sufficient crop rotation data. Organic farmers usually diversify and employ longer course rotations. This would cause shifts in the relationships between different crops for which we could not account in this study. For example, many producers converting from conventional to organic production would likely reduce hectares planted to corn, with more cropped area in small grains and forages. In this sense, our study assumed that organic farmers keep producing what they did as conventional producers. More dynamic modeling in future studies could correct for this inaccuracy.

Synthetic fertilizer savings

We calculated savings on nitrogen, phosphorus and potassium fertilizer for farms converting as follows:

- Conventional fertilizer application rates were taken from OMAFRA recommendations[21–23], focusing on mid-range soil test results, loam soils and mid-range yield objectives, unless otherwise noted in our earlier report. We assumed that all hectares would have been fertilized at such rates prior to organic conversion.
- Fertilizer prices were taken from the Ontario Farm Input Monitoring Project[21].
- The N price (Cdn\$0.47 kg^{-1}) was an average of ammonium nitrate, anhydrous ammonia, urea and nitrogen solution.
- The P price (Cdn\$0.47 kg^{-1}) was an average of mono-ammonium phosphate (MAP), di-ammonium phosphate (DAP) and triple super-phosphate.
- The K price (Cdn\$0.35 kg^{-1}) was for muriate of potash 60%.

Pesticide savings

We undertook detailed calculations of pesticide applications avoided (in kg active ingredient) and the input savings for farms converted, as follows:

- Pesticide use data came from the OMAFRA survey of pesticide use[24]. Adjustments were made to vegetable and fruit production use totals by subtracting Bt, copper hydroxide and sulfur from the savings, as these actives are permitted in organic production. Use patterns of these materials would likely be different as organic farmers have limitations on their use of copper and sulfur, but we were unable to account for this in the estimates, so assumed that the same levels would be used in organic production.
- Pesticide costs are provided on a use weighted basis, using data from the Ontario Farm Input Monitoring Project Survey[25].
- Since not all pesticides were listed in that survey, we used the ones available that generally accounted for 80% of the active ingredient (ai) applied, except for fruits and vegetables where they accounted for about 66%. We assumed that closely related products were the same price if they were not separately listed. The estimate of pesticide costs in vegetables is high due to the cost of rimsulfuron use in sweet corn. The estimates provided here likely underestimate pesticide savings.

Avoided medications in feed

This analysis was carried out to estimate the amount of sub-therapeutic medication that would not be consumed in animal feed resulting from the transition to organic production of beef, swine and chicken (broilers) only as these were the commodities for which sufficient data could be assembled.

Table 1. The multiple benefits of organic agriculture[2].

Regarding environmental degradation:
1. Adopting organic farming helps governments address pollution problems and their costs.
2. Adopting organic farming can reduce Canada's GHG emissions and help farmers adapt to the negative effects of climate change.
3. Organic farming can improve biodiversity relative to conventional farming.
Regarding the need to build consumer confidence in the food supply:
4. Adopting organic farming builds consumer confidence by not using products, practices and processes seen to be controversial by some consumers.
5. Organic farming can improve animal welfare.
6. Organic foods may be nutritionally superior to conventional foods.
Regarding the farm financial crisis:
7. Adopting organic farming can reduce financial pressures on farmers.
8. Adopting organic farming can decrease the need for government farm payments.
9. Organic food prices reflect internalization of historically externalized costs.
10. Adopting organic farming can help with rural community revitalization.

Few Canadian data are available on consumption of medications in feed, so the analysis was adapted from a method used in a US study by Mellon et al.[26]. The first part of the analysis required a comparison of sub-therapeutic antibiotics approved in both Canada[27] and the United States[26,28]. The comparison was frequently straightforward, as the list of approved materials is slowly being harmonized. However, some medications are approved in the United States, but not in Canada, or they are approved as a slightly different formulation, or on different animals or at different growth stages, or they are approved at different doses or for different lengths of time. For these, we made the following assumptions:

- We eliminated from our analysis any medication approved in the United States but not in Canada.
- We eliminated from the analysis any medication/growth stage combination that is not approved in Canada; the largest discrepancies occurred in the broiler analysis, so this is likely the most conservative estimate.
- When it appeared that a slightly different formulation was used in Canada, we considered the Canadian medication equivalent to the United States formulation.
- No veal, pregnant animals or breeding stock were included in our analysis, so no medications used exclusively on those animals were included.
- We substituted Canadian doses for US doses where they differed.
- When multiple dose options were provided in the Compendium of Medicated Ingredients Brochures (CMIB)[27], we used those most related to weight gain and efficiency, not options for treatment of acute conditions; if there was more than one option related to weight gain and efficiency, we chose the one closest to US use patterns.
- We did not include medications that appear to be approved in Canada but not in the the United States, since we had no data on percentage of animals treated to support an analysis.

We used the Mellon et al.[26] estimates of percentage of animals treated, which assumes that treatment patterns between the two countries are consistent. Since there are no public Canadian data on treatment patterns, we do not know how accurate this assumption is. We used their estimates of average days on feed unless there was Canadian information[27] that indicated that a shorter period was required in Canada. We used their estimates of feed intake for swine and broilers. In a few cases for beef, the Canadian doses were reported in ways that required that we multiply them by average daily feed intake for a particular growth stage, so we used standard animal production guides of feed intake to determine those. We substituted the number of animals converted to organic production.

Other assumptions relative to the Mellon et al.[26] analysis include:

- No mortalities.
- No medication combinations in the broiler analysis for which the majority of medications in the combination are not approved in Canada.
- Because the size ranges used in different growth stages were sometimes different from those employed in the United States, no medications used in Canada were included that extended beyond US growth stage categories.

Avoided cost payments

Canadian studies of the full costs of Canadian agriculture are lacking, but US and British studies attempting to account for a relatively full suite of costs have recently been completed[12,13]. Of these, the most pertinent is a US study that builds upon methodologies used in other research, and its extensive agriculture is closer to Canadian realities than those in Britain. The authors, US agricultural economists Tegtmeier and Duffy[13], concluded that US externalized costs of conventional agriculture ranged from Cdn$39.73 to 112.56 ha^{-1}, assuming an exchange rate of $1Cdn = $0.85US. We drew on previous work[2,3] and expert opinion to evaluate the degree to which organic production might reduce these costs (see Table 1 for a summary of organic farming benefits). We conservatively used the low-end range of the Tegtmeier and Duffy costs for two

main reasons: the intensity of production in Canada is generally lower and government program expenditures are lower on a farm area basis. However, just because Canadian governments chose to allocate fewer resources to solving agricultural problems does not mean that they do not exist at a comparable level. For example, pesticide contamination of surface waters is largely viewed as a localized problem, but Canadian monitoring capacity remains limited, although a national indicator is now under development[29]. Given limited knowledge in this area, it is not clear whether water treatment facilities allocate sufficient resources to address what problems may exist.

To produce useful comparisons between organic and conventional production, it is important to focus on the entire farming system or larger food system dynamics as opposed to examining specific elements outside of their larger operating context. It is also important to compare systems that have common components, including comparable management capacities. Clearly, poorly managed organic and conventional systems generate problems. We were interested in structural comparisons, so we assumed good management in systems being compared. In doing so, we have used an agro-ecological framework[30] to analyze how the structure of organic farming offers benefits that are not necessarily associated with conventional farming[2,3]. We also took account of the strength of the current literature, which results, for example, in an assignment of zero reductions to human health costs associated with agricultural pathogens, since the literature in this area has produced divergent results.

Transition payments

The following assumptions guided calculations for our proposed Transition Risk Offset Program and Payments for Environmental Services.

- The payments are set at 10% of the gross revenue loss associated with average yield declines during the transition (see Table 2 for estimated average yield declines in organic commodities and Table 3 for sources providing justification for a range of production systems). This level was chosen to be slightly lower than Europe, where such payments range from 15 to 20% of foregone revenue[31], but at a base minimum suggested for improving adoption of other low-input systems in US studies[32].
- Payments to animal production are on a per animal basis, assuming the same conditions of yield loss and compensation.
- To receive payments, farmers would have to belong to a certification agency, be actively committed to the transition process, and to be participating in mentoring and training programs. Since this element of the program starts in Phase II, farmers who convert in the first 5 years of this strategy would be eligible to receive payments retroactively, based on record keeping provided by the certification agencies.
- Transition year—we reported payments for each of the 3 years of required transition, except in animal production for which the period on farm is less than 3 years.
- Yield decline—estimates were derived from the literature and expert opinion (see Tables 2 and 3).
- Average 5-year yield and prices (2000–2004) were taken primarily from OMAFRA statistics[33], with supplemental data provided by some commodity organizations.

Program expenditures

The elements of the program proposed below met the following criteria:

- They have been shown to work elsewhere and can be adapted to Ontario.
- They strike a balance between cost and positive effects.
- They are relatively straightforward to implement.
- Most have significant cost-sharing opportunities with other levels of government, industry and NGOs.
- Most have the potential for third party delivery, which reduces government overhead costs.

We made a number of assumptions:

1. Ontario would participate in the federal program of organic standards development and accreditation, i.e., it would not set up its own system as has been done by Quebec.
2. Ontario would participate in a national organic logo and associated publicity campaign initiated at a federal level, i.e., Ontario would not develop its own provincial organic logo.
3. For most food safety and quality programming, the organic sector would take advantage of existing federal funding programs[34] and develop a national food safety and quality improvement plan for the sector.
4. Additional elements would be added as existing organizations identified suitable grant programs to provide funding. For instance, consumer education is one area in which such opportunities could be explored, especially in Phase II.
5. Organic farmers would have participated in Environmental Farm Plan (EFP) programs consistent with the existing program[35].
6. New rules for nutrient management[36] and source water protection[37] may require technical adjustments as it relates to organic producers, but we assumed these would not impose additional costs for government.
7. Although the programs were designed to accommodate all farmers, we assumed that it would tend to be small- to medium-sized farms that participated, because their transition challenges might be lower relative to large operations.
8. The distribution of costs by year is usually an average or a graduated increase with a fixed formula, since the rate of uptake of programs is difficult to predict at this point.

Table 2. Yield reduction averages relative to conventional production during 3-year transition to organic in Ontario (comparison with a small- to medium-sized conventional operation).[1]

Commodity	Year 1	Year 2	Year 3	5–10 years
Field crops				
Pasture[2]	0	0	0	Same
Hay and alfalfa[2]	0.10	0.05	Same as conv.	Same as conv.
Spring wheat	0.30	0.20	0.10	0.05
Winter wheat	0.30	0.20	0.10	0.05
Barley	0.30	0.20	0.10	0.05
Fall rye	0.20	0.10	0.05	Same as conv.
Oats	0.20	0.10	0.05	Same as conv.
Buckwheat	0.30	0.20	0.10	0.10
Corn for grain	0.30	0.20	0.15	0.10
Corn for silage	0.20	0.15	0.10	0.05
Canola	0.50	0.40	0.30	0.20
Soybeans	0.30	0.20	0.15	0.10
Flax	0.45	0.30	0.15	0.10
Edible beans	0.30	0.20	0.15	0.10
Other field crops	0.30	0.20	0.10	0.05
Vegetables				
Potatoes	0.40	0.30	0.25	0.20
Other roots	0.40	0.30	0.25	0.20
Tomatoes	0.40	0.30	0.25	0.20
Field				
Greenhouse				
Cucumbers	0.40	0.30	0.25	0.20
Field				
Greenhouse				
Leguminous	0.40	0.30	0.25	0.20
Sweet corn	0.40	0.30	0.25	0.20
Cole crops	0.40	0.30	0.25	0.20
Leafy vegetables	0.40	0.30	0.25	0.20
Tree fruits	0.50	0.40	0.30	0.25
Small fruits	0.50	0.40	0.30	0.25
Dairy[3]	0.20	0.15	0.10	0.10
Beef[4]	0.20	0.15	0.10	0.10
Chicken[5]				
Meat	0.35	0.30	0.25	0.20
Eggs	0.35	0.30	0.25	0.20
Turkey	0.40	0.30	0.25	0.20
Pork[6]	0.50	0.45	0.40	0.30
Sheep[7]	0.10	0.05	0	0

[1] For most field crops, the assumption is that the transition does not start from a forage crop.
[2] Assumes that conventional farmers managed hay and pasture without excess fertilization.
[3] Assumes herd reduction and increased hectares to accommodate increased pasture and hay production.
[4] Assumes integrated operation, birth to slaughter, no feedlots, major yield declines are associated with reduced weight gain. See Ag Ventures, February 2001. Agdex 420/830–3. Available at Web site http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex3458/$file/420_830–3.pdf?OpenElement (accessed 5 January 2009).
[5] Assumes floor operations. Available at Web site http://www.acornorganic.org/pdf/poultryeggsprofile.pdf
[6] Most difficult comparison: assumes small independent hog operation with most feed produced on the farm. Assumes that 100 sows/1000 market hogs versus 100 sows/2000 market hogs in conventional operation. Transition focuses on 6.5% of Ontario operators roughly in this size range. Farrow to finish.
[7] Assumes most conventional sheep operations are low input, so differences are largely due to stocking rates and yield reductions from changes in de-worming agents. Meat only.

Estimating organic market share

Limited data make pinpointing the current and possible future size of the organic food market difficult. We derived our estimates of Ontario's current organic market from multiple sources including national organic market estimates ($1.3 billion[4]), conventional ratios of food retail value/farm gate value, and industry estimates of the percentage of organic production that is exported and organic consumption that is imported. To estimate how

Table 3. Comparing yields in organic versus conventional production: higher order studies.

Product	Country/region	Organic/conventional
Tomato	California, past 10–15 years	1.0[1]
Many crops	Developing countries, numerous projects	1.8–4.0[2]
Cereals	Europe	0.6–0.7[3]
Corn	Major corn regions of the United States, past 10–15 years, experimental station studies	0.94[1]
Soybeans	Five US states, past 10–15 years, experimental station studies	0.94[1]
Wheat	Two research institutions, past 10–15 years	0.97[1]
Dairy	Europe	0.8–1.0 per cow, with stocking rates of 0.6–0.8 LU per farm[3]. Note that some limited data from Ontario suggest that yields can be equivalent[4] and stocking rates higher than Europe[5]

[1] Liebhardt, B. 2003. What is organic agriculture? What I learned in my transition. In: OECD (ed.). Organic Agriculture: Sustainability, Markets and Policies. CABI Publishing, Wallingford, UK. p. 31–49.
[2] Pretty, J. and Hines, R. 2001. Reducing Food Poverty through Sustainable Agriculture. Centre for Environment and Society, University of Essex, UK.
[3] Nieberg, H. and Oppermann, N. 2003. The profitability of organic farming in Europe. In: OECD (ed.). Organic Agriculture: Sustainability, Markets and Policies. CABI Publishing, Wallingford, UK. p. 141–152.
[4] Ogini, Y., Clark, E.A., and Stonehouse, P. 1999. Comparison of organic and conventional dairy farms in Ontario. American Journal of Alternative Agriculture 14:122–134.
[5] Roberts, C.J., Lynch, D.H., Voroney, R.P., Martin, R.C., and Juurlink, S.D. 2008. Nutrient budgets of Ontario organic dairy farms. Canadian Journal of Soil Science 88:107–114.

much organic farmers contribute to the total Ontario organic retail market after 5 and 15 years, we conservatively assumed a 15% annual growth rate in organic retail sales over the first 10 years of the program, and 10% in the last 5 years. We assumed growth rates in the conventional food market of 1.5% annually. We also assumed modest increases in the portion of organic production that goes to domestic versus export markets.

Results and Discussion

Organic targets

Production. Results of the analysis are provided in Table 4. In Phase I, supply increases would come from a combination of new organic farms and expansion of scale and/or enterprises among existing organic operations. For example, organic field crop producers might certify an existing conventional beef herd, or a producer whose home farm is certified organic might subsequently certify another farm within the total operation. Regarding new organic operations, many farms are already organic but not certified, or in the process of transition[38], and many companies are working with conventional producers to gradually bring them into their organic supply chain. Additionally, some new entrants to farming would enter organic production directly.

By the end of Phase II (15 years), 5343 organic farmers would be producing organically in all major commodities. Organic production would occur on about 367,000 ha of land (about 10% of current crop area), and some 1.4 million animals would be reared organically. This figure includes existing and converted acres.

Processing. Processing targets were more difficult to establish because of the very limited current data on organic processing. Of the conservatively estimated 64 certified processors and handlers in 2003[6], the majority fell into the following categories: five in dairy, four in bakery, two in flax, three in fruit, two in nuts, five providing meat processing, three doing beverages, 14 considered packers and handlers and four animal feed. How many were exclusively organic, versus processing both conventional and organic foods, is unclear from the data. Data from the OMAFRA show that the following primary processing organic products are available from Ontario processors: flours, eggs, fruits and vegetables (including fresh cut, roasted garlic and soybeans, and seasoned beans), honey, maple syrup, alternative sweeteners, soup mixes (dry, containing beans), fluid milk and meats. Available in the secondary processing category are: breads, rolls and baked goods (including cookies and pitas, and baking mixes), snacks and cereals (including seeds, chips and popped snacks, snack crackers and nut/fruit/meal replacement bars), beverages (including alcohol, teas, coffees, fruit and grass juices and seltzers, and powder mixes), prepared soups, condiments (including ketchup, salad dressings, miso, sauces, nut and fruit butters, and jams and jellies), chocolates, processed dairy products, pasta, ethnic meals and prepared foods (curries, entrees, pates, baby foods) and ingredients—including starches, gums, flavors and extracts. What percentage, however, of the ingredients of these processed goods are purchased from Ontario producers is not known[39].

Table 4. Five- and 15-year organic conversion targets.

Production	5-year target, 2× current, in ha	15-year target (fraction of conventional)	Hectares to be converted (ha)	New organic farms needed
Crop				
Pasture	10,210	0.08	62,467	Reported with hay
Hay	11,435	0.08	70,071	3411
Spring wheat	408	0.12	5625	Reported with winter wheat
Winter wheat	2550	0.12	35,130	2933
Barley	1535	0.10	9548	575
Fall rye	763	0.15	3562	419
Oats	2113	0.15	5316	597
Buckwheat	989	1.00	1910	152
Corn (grain)	2747	0.05	33,013	Reported with silage
Corn (silage)	485	0.05	5825	2341
Soybeans	14,465	0.10	88,849	2410
Flax	362	1.00	622	37
Edible beans	62	0.10	2398	100
Mixed grains	2107	0.15	8348	665
Potatoes	202	0.10	1476	281
Vegetables	993	0.10	6389	1754
Apples	707	0.25	1407	79
Grapes	34	0.05	307	108
Peaches	40	0.10	231	36
Strawberries	6	0.10	122	50
Sour cherries	8	0.05	42	9
Pears	1	0.05	37	23
Raspberries	2	0.10	37	46
Crop totals	52,217	0.10	342,704	5343
Animal	Head		Head to be converted	
Dairy	6882	0.10	31,959	432
Beef	5046	0.02	43,637	1148
Sheep	1206	0.10	33,397	726
Pork	26,400	0.03	97,500	89
Broilers	11,504	0.003	606,239	909
Turkeys	100	0.01	83,590	7
Layers	25,918	0.05	468,041	904
Animal totals	77,056	0.006	1,364,363	4215[1]

[1] Farms reporting animals are not added to the crop total since it is assumed that all farms reporting animals would also report crops. The ratio of farms reporting animals to crops is slightly higher than the 2001 Census of Agriculture, but this is sensible given that organic producers tend to report livestock to higher degrees than conventional producers.
(For details on calculations and assumptions, see http://www.oacc.info/Docs/OntarioOrgStrategy/TargetOOS_Statistics_sheet1.pdf.)

In 2003, there were a total of 2300 Ontario food processors with registered employees and an additional approximately 800 operated by the owner and/or family members and/or contract employees. The total estimated value of agricultural shipments (2001) was $24.5 billion[40]; thus organic processors would represent about 2% of the total by number of enterprises, and even less by value of shipments. Doubling the number of firms processing organic food within 5 years would be a reasonable target. Sub-sector targets for year 15 were impossible to determine at this point.

A key question is where organic processors will come from. In most food sub-sectors, smaller firms represent the majority, with over half the firms having 20 registered employees or less[40]. Smaller processors tend to focus on local markets, which is the objective of the organic strategies set out in the present paper. However, to optimize production costs, many processors find that they must serve local markets but do so across the country. This often requires a shift to medium scale, or the firm may move to larger markets to accommodate a larger local market when product is perishable. This type of scaling up often has investment challenges.

Plants of smaller scale are often more flexible and accommodate a wider product range, with better capacity for new product introductions. But countering this reality, smaller firms often face cost-effectiveness challenges and often do not have the resources to invest in new products while running day to day operations[41]. Despite these challenges, it is likely that organic processing capacity will come from existing small operations, perhaps many without registered employees, and new small firms that start out as

exclusively organic processors. There are five main areas of processing activity in the province—SW near Windsor, Grand River Region, Niagara, Toronto, Quinte area—and organic firms will likely similarly concentrate.

Avoided costs

Based on the Tegtmeier and Duffy analysis[13], we estimated that with widespread adoption, organic farming could avoid 56% of these externalized costs, or Cdn$22.25 ha^{-1}. As shown in Table 5, we estimate that organic farming can reduce from 0 to 100% of specific externalized costs, depending on the type of negative impact.

At $39.73 ha^{-1}, Ontario cropland (restricted to cropland to make it comparable with US estimates) in 2001 was generating $145.28 million in annual environmental and health costs, many of which are avoidable. These environmental and health costs are currently borne by three levels of government and private landowners.

Input savings

Over the 15 years of the program, converted organic farmers would reduce fertilizer applications by about 43 million kg, pesticide applications by about 296,000 kg active ingredient (8% of pesticides applied on studied crops in 2003), and 7079 kg of antibiotics consumed in animal feed. Financial savings (2004–2005 prices) would amount to about $18.3 million in saved fertilizer applications and $9.1 million for pesticides[42]. Given current trends in input prices, these are conservative estimates.

Programs and expenditures

The plan is organized into two phases. Phase I (a 5-year phase) involves programs to build information, research and development (R&D), market development and technology transfer infrastructure. Phase II (years 6–15) is concerned with the provision of active supports for the process of converting from conventional to organic production. Some Phase I elements would continue into Phase II. In total, the plan comprises 30 elements. Brief program descriptions are provided in Table 6 and expenditures in Table 7.

Transition risk offset and environmental service payments

As the largest proposed program expenditure, this element of the overall program warrants more specific discussion. The objective of this initiative would be to pay farmers some of the revenue lost during the transition period, typically the most difficult period for organic farmers. In addition, this initiative provides a one-time payment for environmental services, an amount that recognizes the farmers' contributions to internalizing some of the costs of conventional production.

With program expenditures of over $39 million (Table 7, Phase II), this element will likely be the most challenging for the government to implement in the current policy climate. Despite recent pilot projects, such as the Alternate Land Use Services initiative in Norfolk County, Ontario, that is paying producers for environmental services[43], many policy-makers are reluctant to adopt this EU-style approach to ensuring environmental improvements with an additional dose of farm financial security.

In this analysis, annual payment levels varied from 0 to $883 ha^{-1}, depending on commodity and transition year. The payment for avoided environmental costs would be delivered 3 years after full organic certification (assuming no intervening loss of certification status post transition). Following on the analysis provided in Table 5, this payment is set at $22.25 ha^{-1} for all crops, except pasture. The benefits of transition, as defined in the Tegtmeier and Duffy study[13], are much lower for pasture (and in fact they did not include pasture lands in their analysis), so we have set the level at $0.5 ha^{-1}, largely to recognize the potential for lower GHG emissions on organically managed pasture. No per head payments are provided for animals, as it is assumed that all converting animal producers have a cropping base for their farm.

We assumed a 30% reduction in financial safety net payouts based on historical payment patterns of net new program costs[44], and assume that the province saves 12% on other costs once making payments for this program. We assumed that program delivery is carried out by existing agencies involved in farm financial safety nets, with additional administrative costs of $200,000 annually. Additionally, to support record keeping, each certification agency would receive a one-time administrative payment per certified farm of $100 × 4854 new organic producers = $485,400.

We also ran several scenarios for different farms to test total payments. This analysis is provided in Table 8. Of the four case studies presented, total payments to farmers would range from $13,000 to 25,000 spread out over 4 years, well within the typical range of average government payments to farmers under present conditions[7].

Market share

Implementation of this plan would allow the Ontario organic sector to capture 51% of Ontario's organic consumption, up from the currently estimated 15%. Organic sales would represent 1.9% of the total retail market after 5 years and 5.3% of the total market after 15 years.

Conclusions

A two-phase, 30 point plan was developed to boost organic production to 10% of agricultural area within 15 years and to capture 51% of Ontario's organic consumption, up from the currently estimated 15%. As with other government efforts, the objective is to stimulate organic production and processing with government initiatives so that sufficient

Table 5. Analysis of conventional agriculture costs (from Tegtmeier and Duffy[13]): How much does organic production avoid?

Damage category	Rationale for level of avoided costs associated with organic adoption	US conventional cost (low estimates only) (Cdn$ ha^{-1}; Cdn$1 = US$0.85)	Organic avoided costs in Ontario (Cdn$ ha^{-1})
1. Damage to water resources			
1a. Treatment of surface water for microbial pathogens	Dramatically lower pathogen loads in compost than slurry, reduce by 50%	0.83	0.41
1b. Treatment for nitrate	Organic does not eliminate nitrate leaching, but in most studies reduces it by 40%	1.32	0.53
1c. Treatment for pesticides	Since organic standards do not permit most synthetically compounded pesticides, especially those with persistence, this need for treatment is eliminated.	0.78	0.78
2. Damage to soil resources	Organic farming reduces soil erosion by 40%[1]	15.68	6.27
3. Damage to air resources			
3a. GHG emissions from crops	Erosion rates reduced by 40%; CO_2 emissions net 50% lower in organic systems due to no emissions from manufacture of synthetic N fertilizers; methane losses comparable; N_2O losses at 20% below conventional production. Net reduction of 50%	1.98	0.99
3b. GHG emissions from livestock	CAFOs are effectively not permitted in organic production because such operations cannot meet organic requirements; composting significantly reduces total GHG emissions. Lower stocking rates and different diets also contribute. Reduction of 40%	1.17	0.47
4. Damage to wildlife and biodiversity			
4a. Honey and pollinator losses	Significantly higher populations in almost all comparative studies; since the US study focuses on pesticide-related losses, reduce costs by 90%	2.87	2.58
4b. Loss of beneficial predators	Significantly higher populations in almost all comparative studies; since the US study focuses on pesticide-related losses, reduce costs by 90%	4.66	4.12
4c. Fish kills from pesticides	Since no synthetically compounded pesticides are used, there would be limited fish kills, although a few permitted biologicals are toxic to fish, so we apply a 90% reduction.	0.15	0.14
4d. Fish kills from manure	Since liquid manure is rarely used in organic production, especially in large storage facilities, such kills would be dramatically reduced. However, there is some possibility of water contamination from organic operations, so this is reduced by 90%.	0.08	0.07
4e. Bird kills from pesticides	Since no synthetic pesticides are used, and biologicals are not associated with bird mortalities, this problem is eliminated.	0.24	0.24
5. Damage to human health; pathogens	Although there is some evidence that pathogen loads can be reduced in organic production, this is an insufficiently studied area to warrant a reduction in costs.	2.91	0
6. Damage to human health: pesticides	Because there can occasionally be occupational exposure problems associated with a limited number of biological pesticides, we reduce this cost by only 80%.	7.06	5.65
Summary of costs and avoided costs		$39.73; $145.28 million total in Ontario	$22.25

Assumptions:
(1) that organic adoption is sufficiently widespread to have an impact in an area;
(2) that the comparison is between well-run organic and conventional operations;
(3) that the averages are blended across a variety of production systems;
(4) in the face of limited data, estimates are always on the conservative side.

[1] We are comparing here conventional systems with simple crop rotations and minimal soil cover and those under organic management with longer course rotations and significant soil cover. Earlier reports of long-term comparative studies[46,47] reported erosion reductions associated with organic production much higher than 40%, but we moderated those results on the assumption that soil erosion rates have generally come down under conventional management. We exclude arid land estimates of erosion reductions, which are usually lower than 40% because they are not pertinent to the Ontario situation.

Table 6. Brief program and outcome descriptions.

Program title	Brief description	Specific outcomes
5.1. Implementation structures		
5.1.1 Establish a roundtable implementation model	Multi-stakeholder roundtable, involving industry, NGOs, scientists and government officials, to guide plan implementation, coordinated by the Organic Council of Ontario	
5.1.2 Provincial interdepartmental committee	Formal structures to direct provincial implementation of strategic plan elements	
5.2 Market data collection	Annual provincial contribution to market studies as part of a multipartite funding initiative	A full data set on organic market, to assist with targeted sectoral strategies
5.3 Organic research and development		Full research programs in areas where organic research is particularly weak at present
5.3.1 Horticulture research program	5-year support for a research coordinator, one PhD student and one post-doctoral fellow	
5.3.2 Animal production research program	Long-term support for primarily poultry, beef/sheep and swine production researchers, currently the most under-represented areas	
5.3.3 Social studies	5-year support for researcher	
5.3.4 Food processing	4-year support for research coordinator, cost shared with the federal government	
5.3.5 Farm business management	Developing production budgets in major commodity areas, including transition budgets to support the transition planning services	
5.4 Training		
5.4.1 Internship programs for non-farm youth	Funding program delivery for three apprenticeship networks that help non-farm youth enter organic farming	60 farm interns annually (300 total), with 25% successfully owning or managing organic farms within 5 years (75).
5.4.2 Incubator farming program	Funding of three third party organizations that offer farmland on a lease basis to new farm start-ups, with infrastructure and mentoring	Pilot supports 15 incubator farmers site^{-1} for 3 years: 45 farmers primarily in horticulture.
5.4.3 Universities and colleges degree/diploma programs	New academic positions (see 5.3) and course development at the University of Guelph's organic Bachelor's program	25–30 graduates yr^{-1} after 10-year support period
5.4.4 Short courses	Introductory and advanced courses for farmers, processors and professionals, building on existing course design and delivery by NGOs and ecological farm organizations	175–225 farmers annually taking intro organic courses; 60 farmers, five processors and 30 professionals per year in specialized courses
5.5 Certification assistance	A 2-year 'quick start' certification subsidy for farms and processors never previously certified, government pays 50%	50 farms and five processors certified
5.6 Production safety nets		
5.6.1 Analysis of organic farmer participation in programs	Fund an analysis of organic farmer participation in production safety net (business risk management or BRM) programs	
5.6.2 Expand organic production insurance program	Enhancing crop coverage in the emerging Ontario organic crop insurance scheme run by Agricorp, which does not add to government costs since a tripartite funded insurance scheme	A full organic production insurance program, with equivalent coverage to that for conventional producers
5.7 Supply Management Marketing Board changes		50–75 new entrants to organic production in supply-managed commodities
5.7.1 Temporary quota and loan programs	All supply-managed commodities develop temporary quota or small farmer licensing programs to encourage new organic entrants that do not already have quota. Costs absorbed by marketing boards.	

5.7.2 Small organic flock licensing programs	For chicken, egg and turkey production, creating provisions for small organic flock direct to consumer sales. Costs paid by licensees	
5.7.3 Check-off changes	To increase organic research, carry out a feasibility study of an organic commission collects dues rather than organic producers contributing to a conventional commodity group.	
5.8 Collaborations to advance food safety	Government food safety program staff work with organic sector, through the Organic Council, to help implement sector-wide food safety initiatives.	Sector-wide food safety plans
5.9 Animating non-retail food distribution channels, especially for low-income markets	Using existing grant programs, a third party applies for 3-year funding to develop non-retail distribution infrastructure (e.g. box schemes, CSAs and buying clubs).	Add 2500 low-income households to purchasing pool with an additional $1.5 million in annual demand
5.10 Processor supports[1]		
5.10.1 Organic business development expertise	One full-time equivalent position for organic processors within the Food Industry Competitiveness Branch of OMAFRA	
5.10.2 Resurrecting orphaned processing facilities	Feasibility study to determine whether abandoned facilities in horticulture and field crops can be adapted to organic requirements	
5.10.3 Incubator processing facility	Using an eco-industrial park model, conduct a feasibility study for small- and medium-scale organic processing	
5.10.4 Capital fund for SME processing and handling	Study the feasibility of establishing a $20 million capital fund at market rates for organic processors in the $0.5–10 million sales range.	
5.11 Support for cooperative production, processing, distribution and marketing	Technical assistance grants cost shared with the federal government 50/50	
5.12 Institutional procurement	Start-up grants for groups of Ontario farmers (and processors) attempting to meet institutional food service requirements	
5.13 Transition advisory service	Funding for a transition planning center with regional coordinators and a network of mostly peer transition planners to work with converting farms and processors	Center supports about 450 new actively transitioning farmers yr^{-1} (courses, plan development) and 10–20 processors
5.14 Transition risk offset and environmental service payments	See main text for details	See main text for details
5.15 Consumer and public education campaigns		
5.15.1 Organic information hotline and web site	Primarily for processors and retailers who are responsible for advertising it, with government cost sharing 50/50 with industry	
5.15.2 Generic POS material for retail	Government pays for development of POS materials which industry buys at post-development costs	

[1] Additional details of processor supports can be found in a supplemental report by Christianson and Morgan[39].

Table 7. Program expenditures (Cdn$).

Years	Expenditure summary (net costs)														
	Phase I					Phase II									
All programs	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**Total**
Program																
5.1 Coordination																150,000
5.1.1 Implementation model	30,000	30,000	30,000	30,000	30,000											50,000
5.1.2 Interdepartmental team	10,000	10,000	10,000	10,000	10,000											150,000
5.2 Market data collection	30,000	30,000	30,000	30,000	30,000											
5.3 Research and development																975,000
5.3.1 Organic horticulture	195,000	195,000	195,000	195,000	195,000											1,875,000
5.3.2 Organic animal production		125,000	125,000	250,000	250,000	375,000	250,000	250,000	125,000	125,000						450,000
5.3.3 Social sciences	90,000	90,000	90,000	90,000	90,000											276,500
5.3.4 Organic food processing	69,125	69,125	69,125	69,125												105,000
5.3.5 Organic farm business management	21,000	21,000	21,000	21,000	21,000											
5.4 Training																975,000
5.4.1 Mentoring	195,000	195,000	195,000	195,000	195,000											450,000
5.4.2 Incubator farming			150,000	150,000	150,000											41,000
5.4.3 Universities and colleges	2000	3000	3000	4000	4000	5000	5000	5000	5000	5000						339,300
5.4.4 Short courses	23,000	50,500	57,400	57,400	57,400	28,200	8200	8200	8200	8200	8200	8200	8200	4000	4000	17,885
5.5 Certification assistance	8942.5	8942.5														
5.6 Production safety nets																30,000
5.6.1 BRM analysis	30,000															0
5.6.2 Organic production insurance	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5.7 Marketing boards																0
5.7.1 Temporary quota	0	0	0	0	0											0
5.7.2 Small organic flock licenses	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25,000
5.7.3 Check-off changes	25,000															0
5.8 Collaborating for food safety improvements	0	0	0	0	0											
5.9 Facilitating non-retail distribution	0	0	0	0	0											
5.10 Processor supports																700,000
5.10.1 Organic business development		70,000	70,000	70,000	70,000	70,000	70,000	70,000	70,000	70,000	70,000					

5.10.2 Orphaned facilities	120,000	40,000														160,000
5.10.3 Processing incubator		225,000														225,000
5.10.4 Capital fund feasibility			40,000													40,000
5.11 Cooperative support	200,000	200,000	200,000	200,000												800,000
5.12 Institutional procurement	165,000	330,000	495,000													990,000
5.13 Transition advisory service						220,000	200,000	200,000	200,000	200,000	200,000	200,000	200,000	200,000	200,000	2020,000
5.14 Transition risk offset and environmental service payments						5,475,966	2,346,843	3,520,264	4,302,545	5,475,966	5,475,966	4,302,545	3,520,264	2,737,983	1,955,702	39,114,045
5.15 Consumer education																
5.15.1 Hotline and web site						200,000	200,000	200,000	200,000	200,000						1,000,000
5.15.2 Genetic POS						75,000										75,000
Total	1,214,068	1,692,568	1,780,525	1,371,525	1,102,400	6,449,166	3,080,043	4,253,464	4,910,745	6,084,166	5,754,166	4,510,745	3,728,464	2,941,983	2,159,702	51,033,730
Phase I/Phase II totals					7,161,085											43,872,645

Table 8. Case studies of transition risk offset and environmental payments: Estimates for a 3-year transition period plus one-time environmental service payment 3 years after certification.

Conventional production	Organic transition payment	Environmental payment	Total
Apple—10 ha	At 1297.99 ha ^{1} = $12,979.99	At $22.25 ha ^{1} = $222.50	$13,202.49
Mixed vegetable (except potatoes)	12 at $2099.49 ha^{-1} = $25,193.88; 8 ha at $6.75 ha^{-1} = $54	At $22.25 = $44.50	$25,292.38
20 ha operation			
12 ha vegetables			
8 ha cover crops			
Cash cropping	75 ha winter wheat × $37.37 = $2802.75	At $22.25 = $6675.00	$19,427.70
300 ha operation	90 ha grain corn × $63.98 = $5758.20		
63 ha in winter wheat	90 ha soybeans × $43.20 = $3888.00		
114 ha in grain corn	45 ha alfalfa/grass hay[1] × $6.75 = $303.75		
123 ha in soybeans	Total: $12,752.70		
Dairy[2]	After organic transition[3]:	100 ha × $22.25 = $2225.00	$16,313.89
100 ha operation	100 ha and 57 dairy cows		
9 ha in winter wheat	9 ha winter wheat × $37.37 = $336.33		
6 ha in barley	6 ha barley × $25.10 = $150.60		
17 ha grain corn	10 ha grain corn × $63.98 = $639.80		
10 ha silage	8 ha soybeans × $43.20 = $345.60		
8 ha soybean	55 ha hay × $6.75 = 371.25		
42 ha hay	12 ha pasture × 0 = 0		
8 ha pasture	57 dairy cows × $214.83 animal^{-1} after 3 years = $12,245.31		
63 dairy cows	Total: $14,088.89		

[1] Sold to nearby livestock operators.
[2] Derived from Canadian Dairy Commission (CDC), Dairy Farmers of Ontario (DFO), University of Guelph. 2005. Ontario Farm Dairy Accounting Project (OFDAP): Annual Report 2004 and Statistics Canada 2001 Census of Agriculture.
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size and momentum allow it to evolve on its own after 15 years. Although the impacts of implementing this proposed strategic plan cannot directly be predicted, the mix of policy instruments is generally consistent with those traditionally used in Canadian agriculture[45], with the exception of payments for environmental services and transition payments. These instruments, however, have been widely tested in other jurisdictions[11], are adaptable to the Ontario scene and are increasingly part of the policy discussion[43].

This overall program would cost the provincial government about $51 million over 15 years. The net total program costs would be significantly lower than $51 million since farmers would have saved almost $28 million in synthetic chemical inputs and received premium organic prices for most of their goods sold. This will unavoidably reduce pressures on the farm financial safety net system and government costs.

Additionally, this program contributes significantly to eliminating the long-term externalized costs of current approaches to agriculture, conservatively estimated at $145 million annually or $2.18 billion over the 15 year life of the program. Not all those costs will be saved within 15 years, but this exceedingly modest investment in organic production, representing only 2.3% of these externalized costs, will generate savings in externalized costs far beyond this one-time investment.

Acknowledgements. We are grateful to the Laidlaw Foundation and the World Wildlife Fund Canada (WWF-Canada) Conservation Fund for financing this research. Members of the Organic Council of Ontario, an organization working to implement many elements of this plan, played a significant role in refining earlier versions of this paper. We very much appreciate the very helpful comments of two anonymous reviewers.

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Renewable Agriculture and Food Systems: 24(2); 137–145 doi:10.1017/S1742170509002518

Meeting market demand in the organic sector: Handler–supplier relationships in the face of tight supply

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Accepted 3 February 2009 **Research Paper**

Abstract

Periodic shortfalls of organic food have been commonplace in the USA. Shortages, created when demand grows faster than supply, have been exacerbated by relatively slow growth of certified organic farmland (in comparison to growth in retail sales) over the past decade. Organic intermediaries, referred to as handlers in the US national organic standards, work with farmers and other handlers in moving organic products along the supply chain, and are often the first to feel the effects of tight supplies at the farm level. These firms have a variety of mechanisms available to procure needed ingredients when organic products are in short supply: contracts with suppliers, encouraging suppliers to transition to organic, working with suppliers to increase their output, working with new suppliers, providing technical assistance with organic standards and production methods, and making less than load shipment arrangements with suppliers. Survey data collected from certified organic handlers are used to identify characteristics that make it more likely that an organic handler will undertake activities with suppliers to affect the supply of organic products. Handlers most likely to work with their suppliers had been in business for longer periods of time, bought from growers or grower cooperatives, and were more likely to be wholesalers. Handlers who consider price as important were less likely to undertake activities with their supplies to increase the supply or flow of organic products.

Key words: organic, certified organic, intermediaries, handlers, farmers, supplier, procurement, agricultural contracts, market demand, supply chain, survey data, logistic regression

Introduction

Retail sales of organic food in the USA grew from $3.6 billion in 1997 to $18.9 billion in 2007[1]. As sales soared, organic foods began appearing in nearly all supermarkets and other mainstream venues like Wal-Mart, Target and Costco. The combination of the widening array of venues selling organic food and growth in consumer demand has placed pressure on retailers, intermediaries and farmers to increase the supply of organic food products. Retailers and intermediaries have felt the effects of farm-level shortfalls of organic products, with the most recent examples being milk, feed and grains. Because of the requirement that land be farmed in accordance with a certifier-approved farming plan for 3 years before its yield can be sold as organic, there is a lengthy lag associated with increasing the total market supply of organic food. Adding to this, historic growth of organic acreage in the USA has been slow, especially when compared to the European Union (EU), which along with the USA makes up about 90% of the worldwide market for organic products.

The natural solution to fill gaps between domestic supply and demand is to import organic products and ingredients, although international trade of organic food is hindered by the lack of harmonization of organic standards across the world. Estimates suggest the USA is a net importer of organic products, but the lack of accounting codes recording the flow of organic food prohibits precise measurement of the value of organic imports[2]. Beyond these difficulties, the idea of importing organic food is controversial because where and how food is produced matters to a significant portion of organic consumers[3]. The discussion about

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importing organic foods peaked when Wal-Mart announced plans to increase their organic product line and become a mass-market provider of organic food. Industry spectators questioned whether the presence of a large company such as Wal-Mart might necessitate a growing reliance on organic imports, since domestic production of organic food would likely be unable to respond quickly enough to the dramatic increase in demand for organic food products.

Organic intermediaries, called handlers, have a central role in the industry, through their purchasing of ingredients, and packing, shipping, manufacturing, processing and distributing organic products. Handlers work downstream with farmers and upstream with retailers, and like the canary descending into the mine, are the first to detect problems with the supply of organic products and ingredients. Because they have knowledge of demand at the retail level, handlers can transmit crucial information to suppliers about marketplace needs. By developing personal business relationships with farmers and other suppliers, in times of tight supply, handlers can increase the quantity of organic products available to their firms as well as increase overall market supply by assisting suppliers with the conversion to organic production or undertaking other direct activities with suppliers.

This paper focuses on how relationships between organic handlers and their suppliers, most often farmers or farmer cooperatives, are used for procuring organic products. Using data from a nationwide survey of US organic handlers, conducted by USDA's Economic Research Service, we examine how handlers work to increase the supply of organic products or access to existing organic supply by using various activities with suppliers. To this end, a series of logistic regressions is estimated to identify which characteristics make it more likely that an organic handler will undertake activities with suppliers to affect the supply of organic products.

Background

Similar to their conventional counterparts, organic handlers add value to organic products as they move through the supply chain, plus face the additional requirement of maintaining organic integrity of the goods. Handling of organic products is regulated by the US national organic standards, which specify that the practices include mechanical or biological methods (such as cooking, baking, curing, heating or drying) or otherwise manufacturing, and the packaging, canning, jarring, or otherwise enclosing food in a container that may be used to process an organically produced agricultural product for the purpose of retarding spoilage, or otherwise preparing the agricultural product for market. Entities that handle organic products are exempt from organic certification if they have gross organic sales under $5000.

While opportunities for certified organic handlers have expanded along with retail sales, expansion has not always been easy in the face of numerous constraints to growth. The best available historical information, obtained via industry surveys of processors, indicates that handlers have long faced a lack of reliable supplies of organic raw materials and high transportation and distribution costs, both of which have limited growth of the sector[4–6]. They have also reported difficulty procuring large enough quantities of organic products to distribute to retailers, locating organic producers to buy from, and gaining access to shelf space in supermarkets[7].

Newer problems have confronted handlers as increasing numbers of conventional corporations began entering the organic sector, particularly after the implementation of the National Organic Standards in 2002. With their growing presence in the organic sector, these large firms quickly increased market demand for organic ingredients, further burdening already constrained ingredient markets. Access to shelf space for their organic products is less of a problem for large conventional companies than for small organic firms, which have been able to gain shelf space by tapping into their extensive distribution networks. Dean Foods, for example, used their existing distribution arrangement to place Horizon organic milk and Silk organic soymilk in conventional supermarkets across the USA, a feat that Horizon, as an independent organic company, was unable to accomplish. That said, during 2005 and 2006, Horizon and conventional supermarkets experienced shortages of organic milk at current market prices, along with other firms in the market[8].

Plans of the quintessential American store, Wal-Mart, to increase their organic product line and become a 'mass-market provider of organic food'[9] heighten old tensions, and signal the prospect of new transformations in the sector. While some in the organic industry see Wal-Mart's presence as an opportunity for growth, others are apprehensive about the possible impacts[10,11]. The benefits of a large player entering the sector are that many people will have access to organic food and that more land will be farmed organically. On the other hand, some argue that, in order to meet the supply needs of Wal-Mart, there will be a shift towards larger organic farms and firms, greater dependence on organic imports, pressure to weaken the USDA organic standards and a downward pressure on prices that will affect domestic producers' profits[10,11].

Regardless of Wal-Mart's success in the organic market, industry forecasters suggest that demand for organic products will continue growing. In order to meet demand in this rapidly increasing market without relying exclusively on imports, the supply of domestically produced organic food must expand. Data indicate that, historically, domestic supply has not grown as fast as demand. In the absence of a direct measure of supply (that is, quantity of production of organic products), an indirect measure (certified organic farmland) is used to indicate farm level changes in the sector. Statistics on organic farmland in the USA, available from 1992 until 2005[12], indicate that organic acreage increased to slightly more than 4 million acres by 2005 from roughly 935,000 acres in 1992. Growth of organic farmland

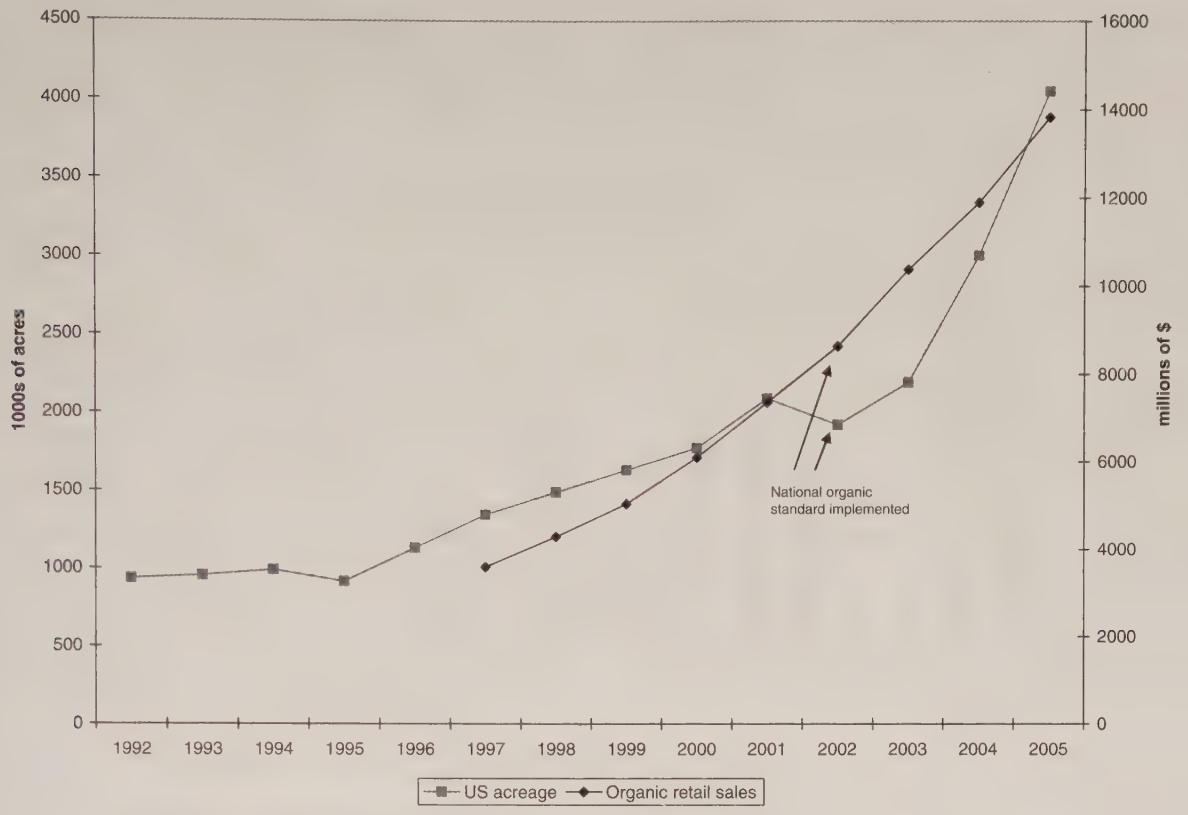

Figure 1. The US organic sector: certified organic farmland and retail sales, 1992–2005. Note: Consistent retail sales data are not available for 1992–1996. Certified organic acreage is not available for years after 2005. Acreage data are not available for 1996, 1998 and 1999; those included here are estimated numbers based on trends.

in the USA increased from 1995 until 2001, and then took a small dip, with growth accelerating after 2002 (Fig. 1)[1,12]. Sales data are not available for the years before 1997; from 1997 until 2005, retail sales steadily increased, and the growth rate in retail sales was faster than the growth rate in certified organic acreage until 2004.

The number of organic farms in the USA has increased at a relatively slow rate, in comparison to the growth in retail sales, from 3587 in 1992 to 8445 in 2005, for an average annual growth rate of 7% (Fig. 2)[12]. The average certified organic farm was 261 acres in 1992, which decreased to 226 acres per farm in 1997. Organic farms remained roughly the same size from 1997 on, with the average farm having 227 acres in 2005. Translating the increase in acreage and farm numbers into increases in production is not possible: no direct measures of organic farm productivity, either current or historical, are available. The only available indirect measure is that organic farming yields are good, and can come close to or match conventional yields[13].

Government policies concerning organic production partially account for the slow growth of organic farmland, particularly when viewed in light of increases in European organic farmland; the US government takes a 'hands-off' approach towards the conversion from conventional to organic production, while the EU subsidizes the conversion to organic production[14]. Other factors are also important. For example, in the USA, many farmers are reluctant to switch to organic production methods. Farmers face a large financial risk as they learn a new way of doing business. During the transition years they face lower yields for crops, which are sold at the lower conventional prices until conversion is complete[15], and, practically speaking, farmers do not reach their top organic production level for approximately 5 years of farming organically[16]. Social pressures also influence the decision to convert, in that farmers converting to organic may be criticized by their neighbors[15,16]. Additionally, recent high prices for conventional corn and soybeans have made it difficult for industry members to get farmers to convert to organic production[17].

While anecdotal evidence indicates that intermediaries work directly with farmers to increase organic supply, a systematic look at how intermediaries and suppliers work together to increase supply has not taken place until now. The nationwide survey of US organic handlers provides new data that allow an examination of the degree of vertical coordination between these two levels of the organic supply chain. At one extreme, anonymous transactions between handlers and suppliers, or spot market sales, represent the least amount of coordination, in that control on the supplier is completely absent. The other extreme is where goods are produced in a vertically integrated firm, and control over the supplier is complete. In between is a range of different levels of coordination. Handlers and suppliers can form strategic alliances, in which a handler passes specific

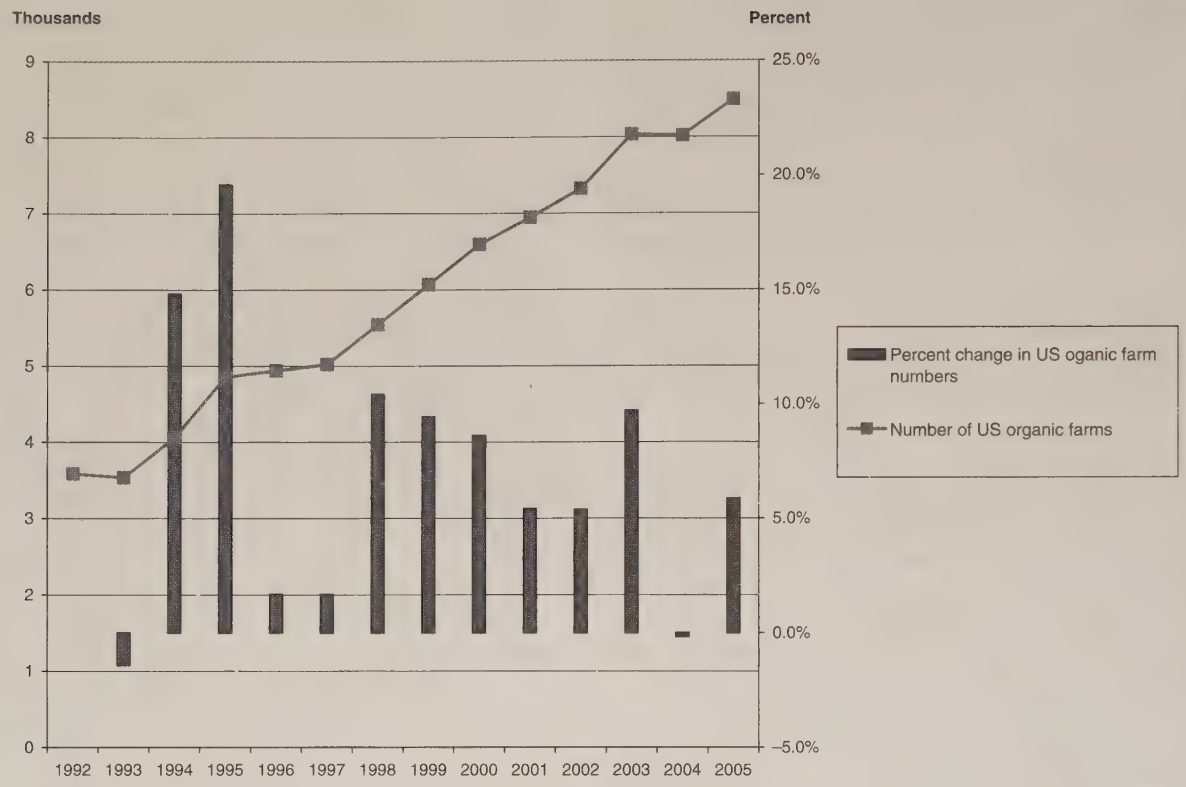

Figure 2. Number and percent change in US organic farms, 1992–2005. Note: Organic Farm numbers for 1996, 1998 and 1999 were not available. Those included here are estimated numbers based on trends.

requirements down the supply chain to farmers without entering a formal contract[18]. Alternatively, formal contracts dictate the terms of the transaction between handlers and farmers.

These types of vertically coordinated relationships are common in the conventional food sector. Fresh produce shippers, for example, use coordinated relationships to control quality, to lock in a supply of high quality produce or to make certain commodities such as tomatoes and lettuce available year-round[19]; in order to maintain year-round supplies of lettuce, production shifts from Salinas, California to Huron, California to Yuma, Arizona throughout the year[20]. Most fresh market lettuce and carrots, and virtually all processed vegetables, are grown under contracts, which specify seed type, variety of plant, fertilizer and other chemical inputs to use. Contracts for processing vegetables have stringent quality standards and sophisticated quality measurement techniques specified[21].

The organic sector conducts a large portion of its business within the framework of vertically coordinated relationships. Findings of the handler survey indicate that nearly three-quarters of all volume is procured through a coordinated relationship, with half of the volume of organic products bought by organic handlers obtained using written, negotiated purchase arrangements while another 24% was procured through informal contracts or handshake agreements. Thirty-six percent of organic volume is procured in the spot market; in contrast, spot markets for all agricultural commodities (including both conventional and organic commodities) govern approximately 60% of all agricultural transactions[22]. These results reveal that the organic sector is highly coordinated in regard to the use of formal and informal contracts when compared to the conventional sector. The remainder of this paper focuses on how vertical coordination is used to increase the supply of organic products.

Data and Methods

Data collected from a nationwide survey of organic processors, manufacturers and distributors (called organic handlers) of 2004 practices are used to investigate the handler–supplier relationship. The survey, drafted with input from stakeholders in the organic sector, including certifiers, farmers, processors, academics and representatives from nonprofit organic organizations, was funded by USDA's Risk Management Agency. The final survey instrument was developed in consultation with Washington State University's Social and Economic Science's Research Center (SESRC), and consisted of 59 questions, covering (1) operational and business practices (e.g., facility function, products produced, labels used); (2) basic characteristics of handling facilities (e.g., gross sales, size of facility, years certified organic); (3) relationships with customers (e.g., marketing outlets used, distance to markets); and (4) relationships with suppliers, including types of suppliers, purchase arrangements (contract versus spot market), as well as assistance provided to suppliers and

attributes and requirements of suppliers. The questions were designed so that specific research questions—such as which firm characteristics influenced the likelihood of that a handler would assist farmers with the transition to organic production—could be addressed.

The survey was sent to the population of all certified organic handling facilities in 2004, which numbered approximately 2790. SESRC administered the survey in late 2005 and early 2006, using the Tailored Design Method[23]. All firms were pre-notified by postcard of the survey. The survey was sent by first class mail, with a $5 incentive, and was followed by multiple carefully timed contacts, including two postcards, a subsequent questionnaire mailing, and phone contacts. Of the total population, 1393 organic handlers completed a 16-page mail survey.

The subsample of interest for this study consists of organic handlers who procure organic products or ingredients through suppliers. Of those handlers returning the survey, 962 reported using certified organic suppliers for procurement purposes in 2004. On average, these handlers purchased organic products or ingredients from 12 individual growers in 2004. To a lesser extent, handlers used marketing or growers' cooperatives, manufacturers and processors, and wholesalers, distributors or brokers for procurement[13].

The survey findings confirmed anecdotal evidence that organic firms faced supply problems, including difficulty meeting market demand. Thirteen percent of all handlers experienced critical shortages of at least one of their organic products at some time during 2004, while another 16% reported insignificant shortages as well. Problems in specific sectors are clear: 26% of milk handlers, 22% of feed and grain suppliers, and 16% of fruit and vegetable handlers had critical shortages that year. These product shortages are mirrored by handlers' difficulties procuring ingredients; 44% found needed ingredients or products in short supply at some point during 2004. The main products in limited supply were coffee, soybeans, milk, seeds, corn and nuts.

The presence of shortages of certified organic products provides firms with an incentive to proactively work to increase the market supply of organic products or their access to organic products. Increasing market supply includes assisting producers to transition to organic methods and working with existing suppliers to increase their supply of organic products, while increasing access to organic products includes developing relationships with suppliers. We posit the likelihood of the following five activities:

1. assist producers in the transition to organic,
2. work with suppliers to increase their production,
3. work with suppliers that have been certified for less than a year,
4. provide technical advice on organic standards or production methods and
5. make smaller (or less than carload) shipment arrangements with suppliers depends on specific firm characteristics, which are classified as handler firm characteristics, buying behavior of the handler and how a handler chooses its suppliers:
   - *Firm characteristics*: Length of time certified organic, the types of suppliers they purchase from, handler function and whether the firm was unable to meet market demand in 2004.
   - *Handler buying behavior*: Whether the firm procures from growers and cooperatives, manufacturers or distributors; whether the firm prefers to buy from local suppliers.
   - *Supplier characteristics preferred by firms*: Supplier knowledge of organic products, whether supplier offers a diverse range of products, length of time the supplier has been certified or product price.

Ex ante, when considering firm characteristics, those that have been certified longer and those with a larger proportion of organic sales are expected to be more likely to work with their suppliers. The rationale underlying this expectation is that these firms that have been certified for a longer period of time 'know the ropes,' and understand how to procure organic products. Firms that sell a larger share of organic products have a greater need for organic ingredients, and thus are likely to work to secure needed inputs in advance. Firms that were unable to meet market demand in 2004 are less likely to have close working relationships with their suppliers during the year.

When considering the variables that represent handler buying behavior, we hypothesize that firms that procure from growers and cooperatives (rather than manufacturers or distributors) are more likely to assist their suppliers in the transition to organic. Handlers who prefer to buy from local suppliers are expected to work closely with their suppliers, given that the proximity of the supplier and handler facilitates building working relationships between the two entities.

The final set of variables represents the characteristics firms seek in their suppliers. Handlers who are willing to purchase from suppliers new to the sector or from suppliers who possess a small knowledge of organic products most likely will have to work closely with their suppliers, by providing assistance with the technical aspects of organic products or assisting with the transition to organic. Thus, those who work with new or inexperienced firms are likely to work with their suppliers. The effect of price is hard to predict. Handlers who consider price as one of the most important factors when procuring ingredients may be purchasing ingredients that are, relatively speaking, in abundant supply and thus do not need to develop close relationships with their suppliers. Handlers who are competing for an especially scarce, needed product, such as feed grain, may be less interested in price, and more apt to work with suppliers.

To examine these questions, a series of logistic models was estimated, to independently evaluate the influence of the 14 characteristics on the odds of a handler taking

Table 1. Descriptive statistics of variables used in the logistic regression series.

	Handlers who use organic suppliers ($n = 962$)	Activities that increase market supply		Activities that increase access to existing market supply		
		Assists with transition ($n = 333$)	Works to increase supply ($n = 279$)	Works with new suppliers ($n = 297$)	Provides technical advice ($n = 280$)	Makes less than carload arrangements ($n = 317$)
Explanatory variables			Mean (standard deviation)			
Handler characteristics						
Length of time handler certified	4.1 (4.5)	5.2 (5.3)	5.4 (4.9)	4.8 (4.6)	5.6 (5.4)	4.6 (5.0)
Share of handler's sales that is organic	35.9 (39.5)	52.2 (40.4)	49.4 (40.4)	48.8 (40.5)	47.4 (40.0)	41.3 (40.6)
Functions as a manufacturer	0.69 (0.46)	0.65 (0.48)	0.64 (0.48)	0.67 (0.47)	0.66 (0.47)	0.67 (0.47)
Functions as a wholesaler	0.22 (0.41)	0.29 (0.46)	0.31 (0.46)	0.27 (0.45)	0.31 (0.46)	0.28 (0.45)
Had a shortage of final product in 2004	0.53 (0.50)	0.41 (0.49)	0.36 (0.48)	0.37 (0.48)	0.39 (0.49)	0.36 (0.48)
Buying practices						
Buys from growers	0.53 (0.50)	0.72 (0.45)	0.76 (0.43)	0.73 (0.44)	0.72 (0.45)	0.62 (0.49)
Buys from grower cooperatives	0.19 (0.39)	0.26 (0.44)	0.24 (0.43)	0.30 (0.46)	0.24 (0.43)	0.25 (0.44)
Buys from manufacturers	0.36 (0.48)	0.35 (0.48)	0.35 (0.48)	0.39 (0.49)	0.37 (0.49)	0.40 (0.49)
Buys from distributors	0.50 (0.50)	0.47 (0.50)	0.45 (0.50)	0.50 (0.50)	0.49 (0.50)	0.52 (0.50)
Buys locally	0.76 (0.43)	0.84 (0.37)	0.81 (0.40)	0.82 (0.39)	0.79 (0.41)	0.75 (0.43)
Preferred supplier attributes						
Consider supplier organic know-how as important/very important	0.92 (0.28)	0.92 (0.27)	0.92 (0.27)	0.89 (0.31)	0.93 (0.26)	0.90 (0.30)
Considers length of time supplier is certified as important/very important	0.78 (0.42)	0.79 (0.41)	0.76 (0.43)	0.74 (0.44)	0.75 (0.43)	0.76 (0.43)
Diversity of supplier offerings important/very important	0.60 (0.49)	0.53 (0.50)	0.52 (0.50)	0.57 (0.50)	0.57 (0.50)	0.58 (0.49)
Supplier price important/very important	0.91 (0.29)	0.89 (0.32)	0.90 (0.31)	0.90 (0.30)	0.87 (0.33)	0.92 (0.28)

specific measures to affect the supply of organic products. Two categories of activities are considered: activities that handlers engage in to increase market supply and those that increase the flow of products to their firm. A dummy variable for each one of these activities is used as the dependent variable in the models estimated (assists with transition, works to increase supply, works with new suppliers, provides technical assistance and makes less than carload arrangements). Each activity was used by approximately one-third of the handlers who procured organic ingredients in 2004. Whether a handler uses contracts was also specified as a dependent variable, but the model did not predict contract use, and thus was omitted from the paper.

Summary statistics for the independent variables used in the study are in Table 1. The first set of independent variables describes handler characteristics. Continuous variables are the length of time a handler is certified organic and the share of a handler's sales that is organic. Discrete variables represent whether the handler is a wholesaler or a manufacturer, and whether the handler was unable to meet market demand at some point during 2004. Buying practices are discrete variables, and identify handlers who buy from growers, cooperatives, manufacturers or distributors. The final group includes discrete variables capturing four features a handler might view as important when choosing a supplier: supplier knowledge about organic products, offering a diverse range of products, length of time the supplier has been certified or product price.

Results and Discussion of Research Findings

The decision to undertake specific activities with suppliers can be modeled as a discrete choice where the dependent variable, y_i, takes on the value of 1 if the intermediary engages in the particular activity, and takes on the value of 0 if it does not engage in that activity. We assume the logistic form for $F(.)$, resulting in the logit model. Based on the logistic distribution, the probability of engaging in a specific activity is

$$\Pr\{y = 1\} = \frac{e^{\beta' x}}{1 + e^{\beta' x}} \quad (1)$$

for $j = 1$, while the probability for not working with the supplier is

$$\Pr\{y = 0\} = \frac{1}{1 + e^{\beta' x}} \quad (2)$$

Either probabilities (P) or the odds ratio, $P/(1-P)$, can be estimated in the logistic model. We chose to estimate the odds ratio rather than probabilities for ease of exposition.

Table 2. Logistic regression results: likelihood of handlers undertaking different activities with suppliers.

	Activities that increase market supply		Activities that increase access to existing market supply		
	Assists with transition	**Works to increase supply**	**Works with new suppliers**	**Provides technical advice**	**Makes less than carload arrangements**
Explanatory variables	Log odds (standard error)				
Handler characteristics					
Length of time handler certified	1.04 (0.03)	1.12 (0.03)*	1.02 (0.03)	1.14 (0.04)*	1.08 (0.03)*
Share of handler's sales that is organic	1.01 (0)*	1.01 (0)*	1.01 (0.00)*	1.01 (0.00)*	1.00 (0.00)
Functions as a manufacturer	0.71 (0.21)	0.83 (0.25)	0.97 (0.28)	0.76 (0.24)	1.07 (0.32)
Functions as a wholesaler	1.83 (0.57)**	1.88 (0.59)*	1.30 (0.39)	2.73 (0.85)*	0.97 (0.29)
Had a shortage of final product in 2004	0.59 (0.16)*	0.38 (0.11)*	0.56 (0.15)*	0.45 (0.13)*	0.32 (0.08)*
Buying practices					
Buys from growers	3.05 (0.84)*	2.69 (0.76)*	2.76 (0.75)*	2.98 (0.86)*	1.42 (0.38)
Buys from grower cooperatives	1.73 (0.51)**	1.47 (0.45)	3.31 (0.99)*	1.57 (0.48)	2.26 (0.70)*
Buys from manufacturers	1.39 (0.37)	0.59 (0.17)**	1.82 (0.49)*	0.92 (0.26)	1.08 (0.28)
Buys from distributors	0.78 (0.21)	0.82 (0.23)	0.91 (0.24)	0.74 (0.21)	1.06 (0.28)
Buys locally	1.34 (0.40)	1.23 (0.38)	1.57 (0.47)	0.84 (0.26)	0.97 (0.27)
Preferred supplier attributes					
Consider supplier organic know-how as important/very important	1.55 (0.71)	1.61 (0.78)	1.09 (0.47)	2.38 (1.17)**	0.98 (0.44)
Considers length of time supplier is certified as important/very important	1.22 (0.39)	1.24 (0.42)	1.11 (0.36)	0.60 (0.20)	0.78 (0.25)
Diversity of supplier offerings important/very important	0.92 (0.24)	0.79 (0.21)	1.45 (0.39)	1.35 (0.38)	1.65 (0.44)**
Supplier price important/very important	0.24 (0.11)*	0.46 (0.21)**	0.49 (0.22)**	0.22 (0.04)*	1.65 (0.76)
Pseudo-r2	0.20	0.22	0.16	0.23	0.12

* Significant at 95% level.
** Significant at 90% level.
Note: An odds ratio of 1 indicates that the variable is equally likely in both groups. An odds ratio greater than 1 indicates that the variable is more likely in the group undertaking the activity than the overall population, while an odds ratio of less than 1 indicates that the variable is less likely in the group undertaking the activity.

The odds ratios reported in the results are the ratios of the likelihood of undertaking the activity by a handler with a specific characteristic (such as a wholesaler) to one without that characteristic (is not a wholesaler). If the estimated odds ratio is 1, then the likelihood of engaging in the activity is equally likely for the two cases, for example, firms that are wholesalers as compared to firms that are not wholesalers. If the estimated odds ratio is greater than 1, then wholesalers are more likely to engage in the activity, when compared to handlers who are not wholesalers; an estimated odds ratio less than 1 indicates that wholesalers are less likely to engage in the activity.

The characteristics that influence the likelihood that a handler will work to increase market supply or to increase access to existing market supply are relatively uniform across the activities (Table 2). Handlers who are wholesalers are more likely to work with suppliers to increase both market supply and supply of products flowing to their firm, when compared to handlers who are distributors, brokers or manufacturers. Handlers who have been in business longer are more likely to engage in activities with suppliers (with the exception of assisting suppliers with conversion to organic), as are those with a higher percentage of organic sales.

With regard to handler buying behavior, handlers who buy from growers or grower cooperatives are more likely to engage in the various activities (both market supply and supply of products flowing to their firm). The effect of preferring to buy from local suppliers did not have a statistically significant impact on whether a handler worked with their suppliers.

In general, handlers do not seek suppliers with specific attributes, including organic knowledge or having a wide range of products available, nor do they consider the length of time a supplier has been certified. However, price did matter: handlers who find product price important are less likely to work with their suppliers, in comparison to handlers who reported that price was not one of the most important parts of the transaction. While these handlers may be purchasing products that are in abundant supply, another possible explanation is that handlers who find price important are willing to risk not being able to find their

needed ingredients rather than locking in supplies in advance, suggesting that handlers may pay a premium when working with their suppliers.

The most interesting finding is that handlers who were unable to supply enough of their product to the market in 2004 are less likely to engage in activities with suppliers to increase market supply or shore up their access to needed ingredients. This finding may be due to the cross-sectional nature of the data, where handlers who experienced shortages in 2004 were not working with their suppliers in 2004. Clearly handlers with shortages of product would have an incentive to undertake efforts to shore up supplies of needed ingredients, and additional data examining the behavior of handlers over time would be useful in this case, where we could test to see if handlers 'learned' from the past; in other words, did the handlers who experienced shortages in 2004 begin working with their suppliers and largely erase their shortages?

Conclusion

The supply chain for organic products has been affected by rapid growth in consumer demand, which has increased the quantity of organic products flowing from farms to retail outlets. Periodic shortages of some organic products, such as milk, feed and grains, have accompanied growth in the market. The profits of handlers—who procure, add value and then sell their products—are affected by these shortages, suggesting that firms that wish to remain viable have an incentive to develop close working relationships with their suppliers. This paper indicates that some firms are more likely to work with their suppliers: wholesalers, firms that buy from producers or grower cooperatives, firms who have been in business longer and those with a larger share of sales coming from organic products. One surprising finding is that a relatively small share of handlers assists farmers with the transition to organic; growth in this aspect of the handler–supplier relationship would benefit the organic sector as a whole.

The findings further suggest that handlers face a trade-off, in that working closely with suppliers may require handlers to focus less on the price of the product and more on the relationship with their suppliers. Further research into this aspect of the supplier–handler relationship would provide insight into how prices are determined in the organic market; that is, whether handlers pay higher prices in order to secure needed products, whether producers accept lower prices in order to conduct business with a reliable company and how handlers select suppliers.

One important question that remains unanswered is how the growing presence of conventional firms in the organic market affects the supply chain for organic products. If handlers who have been acquired by large agribusiness firms and those who are independent organic firms could be identified, tests could be conducted on differences in strategies for sourcing products. On the one hand, independent firms likely have ongoing relationships with suppliers, and should have at least part of their sourcing needs covered. These firms presumably have an extensive knowledge of organic products. In contrast, large agribusiness firms are more experienced with securing large quantities of supply, yet possess less knowledge of organic products. Understanding how these two groups adapt to growing demand may provide insight into long-term strategies for prospering in a competitive environment.

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Renewable Agriculture and Food Systems: 24(2); 146–154 doi:10.1017/S174217050900252X

Biodynamic agriculture research progress and priorities

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Accepted 20 February 2009 **Review Article**

Abstract

Biodynamic (BD) agriculture became the subject of research efforts during the past decades, whereas a part of the scientific community looks at the BD method with skepticism and marks it as dogmatic. Nevertheless, as explored in this review, a fair share of the available peer-reviewed research results of controlled field experiments as well as case studies show effects of BD preparations on yield, soil quality and biodiversity. Moreover, BD preparations express a positive environmental impact in terms of energy use and efficiency. However, the underlying natural science mechanistic principle of BD preparations is still under investigation. In addition, quality determination methods, based on holistic approaches, are increasingly being investigated and recognized. BD farming strives, as manifested in several publications, to positively impact cultural landscape design as well. Summarized data showed that further research is needed and thus encouraged in the field of food quality comparison/determination, food safety, environmental performance (e.g., footprints), and on the effects of BD farming practices on farm animals.

Key words: biodynamic, research, basic experiments, case studies, quality assessment, landscape development

Introduction

Biodynamic (BD) agriculture, as one of the organic (ORG) agricultural farming methods, was proposed by Steiner[1] and the BD farming method is striving for diversified, resilient and ever-evolving farms, which could provide ecological, economical and physical long-term sustainability for humankind. It encompasses practices of composting, mixed farming systems with use of animal manures, crop rotations, care for animal welfare, looking at the farm as an organism/entity and local distribution systems[2], all of which contribute toward the protection of the environment, safeguard biodiversity and improve livelihoods of farmers. Nowadays, there are more than 4200 BD farms in 43 countries, the area of which, over 128,000 ha, is certified according to Demeter standards[3]. Next to the standards of ORG agriculture, Demeter standards demand the use of BD preparations, keeping of farm animals, use of animal manures, and strongly encourage local production and distribution systems using local breeds and varieties. Stringent processing standards are in place as well[3]. The BD method emphasizes a holistic approach toward farming and became the subject of research efforts during the past decades.

However, to what extent can biodynamics be regarded as a scientific category? This review paper will explore and summarize up-to-date peer-reviewed scientific papers, PhD theses and include other sources, where additional information is needed to explain the background and modes of action. Basic experiments, case studies, food quality comparisons and landscape design and its development are expected to differentiate between biodynamics and other production systems. Although significant differences were attained with the use of the BD method, the exact mode of action of BD preparations, which present the greatest difference from the ORG production method, remains unexplained. Published research data will be analyzed and future development will be brought into focus to better understand and explain the BD farming method. Finally, research proposals and future implications are put into the wider perspective.

Basic Experiments

Besides published results of short-term trials and aimed research[4–8], several long-term trials have been effected with the inclusion of the BD farming method and/or BD preparations (Table 1), where all BD preparations, given in Table 2, were used.

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Table 1. The main characteristics of long-term trials, which are based on sound scientific methods and include BD research.

Country of trial	Trial description	Duration of trial	Size of experimental plots	Crop rotation and fertilization	References
Therwil, Switzerland	In the DOK trial biodynamic, organic, conventional farmyard manure and conventional-mineral farming systems are compared with control plots	1978–the present	10 m × 10 m	Crop rotation same in all systems 2 fertilizing intensities (0.7 and 1.4 livestock units) FYM[1], composted FYM[1] with added BD[3] preparations and MIN[2] are used, depending on production system	Pfiffner and Mäder[19]; Mäder et al.[13]; Fließbach et al.[14]
Darmstadt, Germany	With the MIN–ORG trial, maintained at the Institute for Biodynamic Research, the question of mineral versus organic fertilizers is tackled	1980–the present	5 m × 5 m	Same crop rotation and similar soil tillage are used in all treatments Nitrogen (N) input levels are maintained at the same level, whereas MIN[2], FYM[1] and composted FYM[1] with added BD[3] preparations are used to supply N to the soil	Raupp[22]
Bonn, Germany	Effects of traditionally composted FYM[1] against two types of BD[3] composted FYM[1] and a control plot were investigated	1993–2001	6 m × 10 m	Same 6-year crop rotation with similar land-management techniques was used FYM[1] and composted FYM[1] with added BD[3] preparations were used as fertilizers at a rate of 30 t ha^{-1}	Zaller and Köpke[16]
Therwil, Switzerland	Three-factorial experiment with BD[3] preparations, soil tillage and fertilization as investigated factors	2002–the present	12 m × 12 m	Same crop rotation in all treatments FYM[1] or slurry is applied to crops at an intensity of 1.4 livestock units	Berner et al.[50]

[1] FYM – farmyard manure.
[2] MIN – mineral fertilizers.
[3] BD – biodynamic.

Table 2. Numbers of BD preparations, their main ingredients, mode of use and predicted influence.

Number of preparation	Main ingredient[1]	Use	Mentioned in connection with:
BD 500	Cow manure	Field spray	Soil biological activity
BD 501	Silica	Field spray	Plant resilience
BD 502	Yarrow flowers (*Achillea millefolium* L.)	Compost preparation/inoculant	K and S processes
BD 503	Chamomile flowers (*Matricaria recutita* L.)	Compost preparation/inoculant	Ca and K processes
BD 504	Stinging nettle shoots (*Urtica dioica* L.)	Compost preparation/inoculant	N management
BD 505	Oak bark (*Quercus robur* L.)	Compost preparation/inoculant	Ca processes
BD 506	Dandelion flowers (*Taraxacum officinale* Web.)	Compost preparation/inoculant	Si management
BD 507	Valerian extract (*Valeriana officinalis* L.)	Field spray, compost preparation/inoculant	P and warmth processes

[1] The procedure of preparation and fermentation is described in detail by Steiner[1].
BD preparations are designed to be used together on a farm/farming system.

Table 3. Yield comparison of some crops under different agricultural production systems.

	Wheat yield			Potato yield			Rye yield			Grass–clover yield			
Treatments	**CON[1]**	**ORG[2]**	**BD[3]**	**CON[1]**	**ORG[2]**	**BD[3]**	**CON[1]**	**ORG[2]**	**BD[3]**	**CON[1]**	**ORG[2]**	**BD[3]**	**Source**
	110	99	100	154	102	100	n/a	n/a	n/a	125	92	100	Mäder et al.[13]
	n/a	99	100	n/a	101	100	n/a	100	100	n/a	91	100	Zaller and Köpke[16]
	104	99	100	103	94	100	126	94	100	n/a	n/a	n/a	Raupp[22]
	n/a	No difference		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	Berner et al.[50]
Average	107	99	100	128.5	97.5	100	126	97	100	125	91.5	100	

Yield relative to BD = 100.
n/a – no data available.
[1] CON – conventional or mineral treatments.
[2] ORG – organic treatments.
[3] BD – biodynamic treatments.

BD preparations (Table 2) are one of the main features of BD agriculture. The thoughts behind the preparations are unconventional and sometimes difficult to understand[2] and the up-to-date underlying natural science mechanistic principle of BD preparations is still under investigation, whereas some attempts have been made to explain the mode of action. Effects were first explained as a normalization (normalizing yields under low-yielding conditions) or compensation (BD preparations compensating for lower N fertilization) effect, where both explanations leave many open questions[9]. A systems response and adaptation model was suggested as a possible explanation, where the effects of BD preparations do not depend only on their properties and mode of application. Foremost, properties of soils, plants, environmental conditions and how they interact are suggested as factors, which determine the effects of BD preparations to the greatest extent[9]. Moreover, BD preparations are applied in small quantities of 4–160 g ha^{-1}, where physical or biological effects seem unlikely[2]. However, bioactive ingredients, such as herbicides, have also been found to have a great influence in small (less than 10 g ha^{-1}) amounts[10]. In addition, BD preparations were also shown to have hormone-like effects[11]. To better understand the mechanisms behind the BD preparations and to determine ongoing processes in plant physiology, further research designed to separate the effects of the preparations from other aspects of BD farming is needed.

Microorganisms at work

Experimental results show effects of BD preparations not only on yields (Table 3), but also on some ongoing processes in compost piles and in the long term in the soil. Carpenter-Boggs et al.[5] report higher average temperatures (3.4°C higher compared with the control pile) throughout the active composting period, whereas Zaller[8] measured no significant differences in the average temperature of BD and conventional (CON) compost piles. BD-treated compost also contained 65% more nitrate in the final samples, respired carbon dioxide (CO_2) at a 10% lower rate, and had a larger dehydrogenase enzyme activity to CO_2 production ratio[5]. Carpenter-Boggs et al.[5] suggest that BD preparations caused these effects through their bioactive ingredients or by serving as microbial inoculants. In addition, the microbial population in BD preparations was found to be substantial[12], where bacteria population ranged from 3.45 to 8.59 $\log_{10} g^{-1}$. Also a population of fungi was found in the preparations 502 and 506 (5.30 and 4.26 $\log_{10} g^{-1}$, respectively). Several bacterial and fungal strains showed a potential for suppressing fungal plant pathogens[12]. This could also be the reason for the significant and clear-cut difference in dehydrogenase, protease and phosphatase activities with respect to the farming systems in the DOK (Biodynamic, Organic and Conventional agriculture long-term comparison) trial, where highest values were measured for the BD system[13]. Microbial biomass nitrogen also differed significantly and was highest in the BD system with 59% more than that in the CON–farmyard manure (FYM) system[14]. Furthermore, the microbial biomass carbon was 35% higher in the BD system, compared with the CON–FYM system[13,15]. In contrast, Zaller and Köpke[16] report no differences between treatments in regard to microbial biomass carbon, where untreated FYM and FYM treated with BD preparations were applied (Table 4). In both cases, microbial biomass carbon was significantly higher than on control plots[16], which leads to the conclusion that FYM had an important effect on the soil microbial biomass build-up. Wada and Toyota[17] went a step further and discovered that FYM applications add to the stability of soil biological functions, where microbial and fungal populations show resilience and resistance against disinfection. In addition, FYM contributes toward a changed soil nitrogen composition and higher rates of protein amino acids, which bind nitrogen in the soil[18]. However, differences between treatments do not seem to depend solely on amino acid supply from manure. An altered amino acid metabolism in the soil also influences soil amino acid composition and contents. Soils receiving FYM with BD preparations have a lower catabolism/anabolism ratio than soils receiving non-prepared FYM, which results

Table 4. Soil organic matter carbon (C_{org}) change, microbial biomass carbon (C_{mic}) content and dehydrogenase activity depending on the production system.

Trial site soil	Sampling depth (cm)	Soil C_{org} beginning (%)	Soil C_{org} change over the trial period (soil C_{org} beginning = 100)			Soil C_{mic} content (CON or MIN = 100)			Dehydrogenase activity (†µg TPF $10\,g^{-1}$; ‡µg TPF $g^{-1}\,h^{-1}$)			Source:
			CON[1]/MIN[2]	ORG[3]	BD[4]	CON[1]/MIN[2]	ORG[3]	BD[4]	CON[1]/MIN[2]	ORG[3]	BD[4]	
Haplic luvisol	0–20	1.42–1.51	85/n/a	91	101	100/81	117	134	132/87†	175†	226†	Fließbach et al.,[14]
Fluvisol	0–20	n/a	n/a	n/a	n/a	100/n/a	125	125	88†	130†	130†	Zaller and Köpke, 2004[5]
Sandy orthic luvisol	0–25	1.05	n/a/79	91	100	n/a/100	114	126	75.9†	109.1†	121.9†	Raupp[22]

n/a – no data available/non-applicable.
[1] CON – conventional or control treatments.
[2] MIN – mineral treatments.
[3] ORG – organic treatments.
[4] BD – biodynamic treatments.
[5] Estimates are given from figures.
‡, † Note that results are given in different units; TPF, triphenylformazan.

also in a more intensive humification process. The explanation for the influence of BD preparations on anabolism is yet to be found[18].

Biodiversity

In this sense, the effects of ORG and BD farming practices are difficult to separate in terms of macro flora and fauna diversity. In the DOK trial, weed species diversity and arthropod diversity (such as carabids, spiders and staphilinids) were interrelated and were highest in the ORG and BD treatments over the period of 21 years[13], which indicates a good site quality. Fließbach et al.[14] report a less dense, but more diverse weed flora in BD and ORG plots. Furthermore, BD and ORG treatments affect earthworm species composition[16] and quantity[16,19]. Significant differences between the BD and ORG treatments are reported for earthworm biomass and quantity in one trial[19] and species composition and biomass in another trial[16].

However, the BD farming method affects the diversity of soil micro flora and fauna more clearly, where various scientists have come to similar conclusions on the basis of long-term trials. When looking at the complexity and diversity of the microbial food web in soils, the metabolic quotient for CO_2 (qCO_2) indicates the economy of microbial carbon utilization[20]. Higher qCO_2 values can indicate young microbial communities with greater energy requirements to maintain itself, whereas lower qCO_2 values, which were also found for long-term (more than 8 years) cultivated BD soils, indicate less stressed soils and thus diverse and highly interrelated soil communities[11,14–16,18]. In line with these findings, Carpenter-Boggs et al.[6] measured higher qCO_2 values for soils amended with BD compost in a 2-year short-term study.

Environmental impacts

Soil organic matter is an important indicator of the soil organic carbon pool in soils. Increasing the amount of carbon stored in vegetation and soil (also called carbon sequestration) is a preventative measure toward slowing carbon dioxide (CO_2) build-up in the atmosphere[21]. Soil organic carbon was maintained at the same level for over 21 years and even showed a small gain in the BD system at the DOK trial, whereas the other farming systems investigated all had a net loss of soil organic carbon[14]. Similarly, soil organic matter in the MIN–ORG (mineral versus organic fertilization) trial was maintained at the same level only in the BD, whereas it declined in the FYM and mineral treatments[18,22]. Farm-scale comparisons also show differences between conventional and BD farms, where long-term BD cultivation results in higher soil organic matter levels[23,24]. Next to CO_2 and methane, also nitrogen in the form of nitrous oxide plays an important role in greenhouse gas emissions from agricultural land use[25]. With the rising use of supplemental nitrogen added to soils, nitrous oxide emissions also increase and might become a more urgent issue in tackling greenhouse gas emissions from agriculture

than CO_2 is today[25]. When we look at the DOK trial, the ratio between yield levels and nitrogen applied turns out to be highest in the BD and ORG systems, when compared with the conventional and mineral-fertilized systems and ranges from 2:1, 2:1, 1:1 to 1:1.2, respectively[13], indicating more efficient use of the nitrogen supplied in BD and ORG systems. Moreover, the BD system contained higher levels of total soil nitrogen on account of soil organic matter and soil microbial biomass when compared with the other systems investigated[14].

In addition, rising energy prices will eventually intensify interest in the search for farming systems, where energy efficiency would consistently increase and consequently energy consumption per unit will be lower[26]. However, interest is already present, as long-term studies and farm comparisons have been carried out comparing the energy efficiency of different farming systems. Results show better performance of ORG systems[26], as well as the BD system[13]. As mentioned before, yields are lower in the BD system (compared with the CON–FYM system), but so is the energy consumption: up to 50% lower mainly due to non-use of external production factors, such as mineral fertilizers and pesticides[13]. This leads to a more energy efficient production in the BD system (20–56% better than CON–FYM), in terms of energy consumption per crop unit of dry matter and energy consumption per unit of land area[13]. Less fossil energy used results in less carbon dioxide being emitted to the atmosphere and thus has a direct impact on global climate change mitigation[21].

Case Studies of Production Systems

The first peer-reviewed study directly comparing BD and CON farms was carried out in New Zealand on 16 farms[23]. BD farming practices for at least 8 years resulted in higher soil organic matter contents, increased quality of soil structure, increased microbial activity and higher numbers of earthworms. BD farms were financially as viable as their CON counterparts.

Droogers and Bouma[24] compared BD and CON soils on two neighboring farms, where each farming practice has been applied for at least 70 years. They found significant differences in soil organic matter (SOM) content and water availability in favor of BD soils. In addition, soil density, and thus compaction, was lower in BD soils. Initial research provided data for a simulation model, in which BD farming practices expressed higher yield potential, long-term stability and sustainability than CON soils.

Several comparisons between BD and CON farms have been effected in Australia, where the main focus was on phosphorus (P) availability in relation to arbuscular mycorrhizal fungi, since P is a limiting nutrient in Australian soils[27]. According to Ryan et al.[28], there is a strong negative correlation between the levels of P (soil extractable and in pasture shoots) and arbuscular mycorrhizal fungi colonization in white clover and rye grass, where BD plants and soils contain less extractable P, but have higher levels of arbuscular mycorrhizal fungi colonization. Also, a steady decline of arbuscular mycorrhizal fungi in two out of three CON farms was observed. However, it is suggested that higher arbuscular mycorrhizal fungi colonization cannot compensate for the lower levels of soil extractable P in the final yields of BD systems. It is discussed that nutrient mobilization from soil minerals is not the only benefit of arbuscular mycorrhizal fungi. Frey-Klett et al.[29] report that fixation of atmospheric nitrogen and protection of plants against root pathogens are also among the myriad benefits of arbuscular mycorrhizal fungi and mycorrhiza helper bacteria. Raupp[22] also reports a higher density of roots on plots treated with BD preparations. Mycorrhiza helper bacteria could be the possible reason for this effect, as they have been proved to stimulate lateral root formation and thus increase potential root–mycorrhiza interaction points[29].

Burkitt et al.[30] compared ten BD and CON dairy farms for 4 years in northern Victoria and New South Wales. In some points, findings are comparable with results of long-term systems trials done in Europe, where soil P has a negative balance. The N and K balance, however, is reported to be non-significantly different between BD and CON farms. Soil organic carbon and soil microbial biomass are also reported to be equal between the farming systems. In addition, earthworm biomass was greater in the CON system on account of one earthworm species, where no information was given on the number of earthworms. Burkitt et al.[31] also report lower milk yields on BD farms on a per hectare and per cow basis. A significantly greater number of chemical treatments per cow were used on CON farms. However, this did not result in reduced parasitic infection, for infection levels were similar on both farm types. In addition, somatic cell count was higher on farms under BD management, where, in turn, significantly fewer chemical treatments were used. Information on incidences of clinical mastitis and longevity of animals, however, is not provided. Burkitt et al.[31] suggested the use of certified inputs on BD farms to increase milk fat, protein and production levels, but did not give further details. This was the only published study found that dealt with farm animals and BD farming practices; thus a serious lack of research projects/results is found and research in this area is strongly encouraged.

The difference between Australian BD farms reported in studies and other BD field trial comparison studies and farm comparisons is, however, that in Australia only preparation BD 500 was applied 1–2 times each year[27]. Also Nguyen and Haynes[32] report only preparation BD 500 being used on a BD farm in New Zealand. As discussed in the professional literature, however, the preparations were designed to be used together and only as such can they have the desired effectiveness. In addition, because of all-year grazing farming systems, Ryan and Ash[27] report no additional organic fertilizers added to soils for over 17 years. Nguyen and Haynes[32] also report no organic or inorganic fertilizers being used on BD soils and as a consequence also lower yields in a 4-year crop rotation (without pastures). In

addition, results of previous studies were confirmed, which indicate BD farming systems as more energy efficient (both in terms of crops and animals) on a per hectare basis but at the same time also more labor intensive than conventional farms[32].

BD wine grape production is also increasingly attracting attention, as some of the world's prestigious wine producers have started to use BD practices in the past decade[7]. Research followed suit and experimental results suggest that BD practices have an effect on wine grape canopy and chemistry, whereas no significant effects on soil fertility parameters were shown in a 6-year on-farm comparison trial between ORG and BD practices in an organic vineyard in California[7]. Probst et al.[33], however, measured significant differences in soil fertility between CON and BD soils on farms with a long history of BD (since 1981) and CON cultivation. Results are in accordance with the findings stated in Table 4. More research is needed to make conclusive statements on quality performance and a long-term systems comparison trial in wine grape production would be of great scientific and practical value.

Quality Assessment

Biocrystallization and the capillary dynomalysis (or Steigbild) method are two so-called picture forming or holistic methods to assess food quality and origin. Although originating in the 1930s, in recent years they have gained more attention as innovative quality concepts[34], not only in connection with BD, but also with ORG agriculture. The methods have been developed from the viewpoint that living organisms do not just exist as substances, but have structuring and organizing properties (i.e., one can know the exact composition and quantity of elements an apple has, but still cannot 'produce' an apple by mixing those sub-stances). These properties control the form and function of an organism[35]. At first, soluble extracts of the desired food product are prepared according to the defined working standards of each method, which have been up-to-date validated and tested on several samples originating from controlled field system comparisons[34]. Furthermore, a Triangle network of laboratories dealing with bio-crystallization (University of Kassel, Louis Bolk Instituut and Biodynamic Research Association, Denmark) was established, whose goal is to develop uniform ISO standards for the evaluation of biocrystallograms and dynomalysis pictures[36]. Next to the introduction of computer image analysis[37], a modified method of panel evaluation of obtained images, using a defined set of ten criteria, was tested and successfully applied[34]. With the use of these methods, however up-to-date, one is able to discriminate only products originating from controlled field trials with different production methods, and thus create reference lines. Plants grown in different climatic and environmental conditions express different qualitative parameters and therefore one is unable to make direct comparisons and conclusive statements on the quality of such plants, which is also true for sensory evaluation methods. Recent promising results from renowned institutions and an increasing number of dissertations in the past years could spur even more interest and acceptance of picture-forming quality determination methods.

Landscape Development in Relation to Biodynamics

The idea of a farm organism or farm individuality is one of the core principles of BD agriculture[1]. Usually it indicates that farm management should minimize nutrient and energy inputs in order to make the farm self-supporting and autonomous[38], which is true also for ORG farms. But it also encompasses a broader idea of the farm placement in its surroundings, the involvement of the people working on the farm, a balance between the sub-systems or 'organs' of the farm (arable crops, pastures, livestock, horticulture, etc.) and the elements of nature, such as forests, heaths, moors and watercourses[38]. In addition, Ho and Ulanowicz[39] provide supportive arguments for an organisms point of view upon sustainable systems, based on thermodynamics. If we extend this point of view to a greater scale, a farm also plays an important role in landscape design and development. For this reason, a bottom-up, present situation improvement approach toward landscape design on farms has been developed, where it is aimed to develop nature-compliant agricultural systems, starting with the acceptance of the natural conditions and developing them according to the needs of the society[38,40]. The Goethean-phenomenological approach has, next to CON methods and solutions, an integral part in this method of landscape assessment, design and development[41]. In conjunction with the above-mentioned methods this bottom-up approach resembles participatory action research, where researchers are not merely observers of the system, but actively take part in the process of shaping it[42]. Moreover, it is argued that sustainable and ecologically sound management of the landscape cannot be achieved only by top-down planning and regulations, but rather with bottom-up, individual and participatory landscape development[40]. Indeed, solutions to problems of one farm do not necessarily solve the same type of problem on another farm and tailor-made solutions should be applied, where demanded[38]. Encompassing a broader set of goals than just landscape design, Helmfried et al.[43] used participatory action research methods to research and shape local, sustainable and environmentally friendly food systems. Linking both approaches with a goal of improving agricultural and natural systems is a promising future perspective.

Conclusion

Many questions on BD farming practices have been addressed in the past decades and results have been published in more than 30 peer-reviewed scientific papers. We

have a better understanding of the effects of BD farming on soil physical, chemical and biological properties, crop growth, yield, processes in soils, etc. BD farming practices are also gaining importance in the face of increasing climate change, energy scarcity and population growth, where they indicate a more resilient, diverse and efficient system. In this sense, BD farming presents a viable farming method, which is worthy of study in more detail on its own account. But what are the priorities in moving forward? Is getting a deeper understanding of the exact mode of action of BD preparations one of them? Until now no fully satisfactory natural science mechanistic principles explanation has been provided. However, the systems response and adaptation model[9] does give a partial, but promising, explanation. But still, does this lack of clarity make the BD method unscientific? There is also no satisfactory explanation on the pathways and mechanisms of soil organic matter equilibrium establishment in soils[44], but the topic is still considered to be of high research interest to scientists. So in order to better understand the role and effects of BD preparations, some methods such as photosynthesis measurements and isotope marking could also be taken into consideration. It is important to search for inspiration in the 'Agricultural course'[1], but also make a step ahead and develop new ideas, research current challenges we are faced with[45] and build new, yet undiscovered perspectives of BD agriculture, while taking into account over 80 years of experience[46] with the BD method.

What about energy efficiency on a wider scale (production to consumption)? Does it make a difference if the preparations are made on-farm or bought from a distant location? Does this affect the effectiveness of the preparations? Must the making of the preparations with the use of animal organs stay as given by Steiner[1]? Or do we need to move forward, explore new possibilities and develop an understanding of the reasons behind given procedures? This is especially an important issue in the face of recent stringent EU hygiene and sanitary regulations[47], which were put in place because of animal diseases that originated in industrial farming. What about research on farm animals? Moreover, is there a difference between BD-prepared compost of animal and plant origin? How does this affect soil fertility and health? And after all, do we need to make more production systems comparison trials? If yes, how well defined are the systems to be compared? And what are the areas of interest to compare? Food quality is certainly a still highly discussed and debated area, which would deserve more attention on this account.

A working group of researchers and professionals, who have gathered in an active process to exchange thoughts, experiences and research results[48], is certainly a signpost into the future. Also a web portal on biodynamic research[49], which was recently put into practical existence, could facilitate the exchange of ideas, thoughts and results. A worldwide network of farmers, researchers, advisors, teachers and others interested in BD farming could contribute toward naming and addressing questions from everyday practice in order to make important steps toward a more sustainable, healthy, prosperous and secure future.

Reviewer's Response

At the Editor's suggestion we are including a reviewer's perspective in order to broaden the understanding of the subject matter:

'My personal perspective is that the authors do not need to ask whether BD can be regarded as a scientific category or even point out that part of the scientific community looks at it with skepticism and marks it as dogmatic. There are over 4200 farms around the world that are certified as BD so it is clearly worthy of study. There are also many research studies and publications identifying the benefits of organic farming and the ability to maintain yields and improve soil health with organic farming methods. To my knowledge BD includes all the key components of ORG so what is true for ORG is true for BD.'

Acknowledgements. We thank both anonymous reviewers for their constructive and useful criticism that has improved this paper, especially reviewer no. 2 for motivating us to extend the 'Conclusions' section. This review is the initial part of a future PhD thesis, based on two research projects (L4-957-0482-06 and J4-9532-0482-07) that are funded by the Ministry of Higher Education, Science and Technology of Slovenia. We acknowledge the Ministry of Higher Education, Science and Technology of Slovenia for financial support.

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Renewable Agriculture and Food Systems: 24(2); 155–162 doi:10.1017/S1742170509002543

Reducing food insecurity in developing countries through meat production: the potential of the guinea pig (*Cavia porcellus*)

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Accepted 17 March 2009 **Review Article**

Abstract

Global poverty and food insecurity continue to remain critical issues, especially in rural areas. Developing and fostering agricultural systems that not only require low to moderate amounts of economic capital and few external inputs but also maintain and enhance the resource base of production are key features of sustainable agricultural development. Sustainable agricultural development, including diversifying smallholder production to include livestock, is a pragmatic approach to address both rural poverty and food insecurity. Livestock play important roles in the lives of humans as converters, recyclers and banks of nutrients. Smallholders raise a diversity of livestock species and often raise multiple species simultaneously. High fecundity, diet flexibility and adaptability to a wide range of housing and management approaches are critical traits of livestock species well suited for producing meat for home consumption and marketing in the context of rural smallholders. Swine (*Sus scrofa*) and chicken (*Gallus domesticus*) meet many of these criteria and are well known livestock species. This paper examines the potential for a less common species of livestock, guinea pig (*Cavia porcellus*) to enhance food security and increase household income of rural smallholders. Although cultural acceptance of guinea pig as a source of nutrition and income is less ubiquitous than that of swine, chicken and other species, the biological, ecological and economic advantages of guinea pig deserve further examination by those working to alleviate global poverty and food insecurity.

Key words: animal protein, development, guinea pigs, livestock

Food Security, Rural Poverty and Smallholder Farms

Food security is broadly defined as having physical, social and economic access to sufficient quantities of safe and nutritious food to meet dietary needs for a healthy life[1]. Global poverty and food insecurity, particularly in rural populations, remain critical issues despite ongoing efforts to address these inequities[2–4]. Seventy-five percent of the developing world's poor live in rural areas and rural populations depend primarily on agriculture for their livelihoods[5,6]. More than 820 million people in developing countries are undernourished, with hunger being concentrated in rural areas[2]. Development based on the principles of sustainable agriculture, fostering agricultural systems that require little capital and few external inputs and that maintain and improve their resource base, is a pragmatic approach for addressing these concerns[6,7].

About half of the world's hungry live in smallholder farming households[8]. The definition of a smallholder depends on geographic location and social context[6,9,10]. For this discussion we will consider smallholder farms to be farms that are $\leqslant$2.0 ha in size, where labor is provided almost exclusively by family members that live on or near the farm, and a significant portion of the farm products—food, fiber and fuel—are consumed directly by the owner–operator family. Diversifying smallholder production to include animal husbandry is a promising strategy for reducing both food insecurity and poverty by providing consumable protein and marketable products[7,9,11,12].

The quantity of available food resources affects food security in direct and indirect ways. Consuming grain-fed animals rather than directly consuming grain means that more total calories must be produced to achieve the same level of human caloric intake. This thermodynamic reality has served as the basis for calls to reduce and even

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Table 1. Reproductive and growth characteristics of selected livestock species for meat production[1].

Name common (scientific)	Age at mating (days)	Estrus cycle (days)	Gestation period (days)	Litter size (no.)	Market age (days)	Market weight (kg)	Dress percent (g 100g)
Cattle (*Bos taurus*)[2]	440	19	280	1–2	550	570	56
Chicken (*Gallus domesticus*)[3]	150	Cont.	21[9]	6–9	70	1.7	76
Goat (*Capra hircus*)[4]	360	20	150	1–3	244	30	50
Guinea pig (*Cavia porcellus*)[5]	90	16	68	3–4	90	1.1	56
Rabbit (*Orytolagus cuniculus*)[6]	180	Cont.	30	5–8	120	2.0	55
Swine (*Sus scrofa*)[7]	220	21	114	8–10	210	100	70
Sheep (*Ovis aries*)[8]	300	16	147	1–3	236	43	54

[1] Growth and performance are heavily influenced by nutrition, environment and genetics. Characteristics presented are general guidelines for smallholder farms.

[2] 52,66–68

[3] 37,52,69

[4] 70–74

[5] 40,41,47–49

[6] 38,52,75,76

[7] 31,32,77,78

[8] 79–82

[9] Incubation period.

eliminate animal protein from human diets[13]. Vegetarian diets can be nutritionally adequate if sufficient attention is paid to nutritional needs and if a diversity of foodstuffs is available[14–17]. However, nutritional quality and diversity are also important factors of food security.

Foods of animal origin not only supply protein and energy, but also provide a variety of micronutrients that can be difficult to obtain in adequate quantities from plant sources alone[18]. Because meat, milk and eggs have a greater concentration of nutrients with high biological availability, achieving a nutritionally balanced diet by consuming both plant and animal foods is easier and in many cases more practical to do than following vegetarianism[19,20]. Evidence supports the conclusion that pre-historic humans healthfully consumed a mix of plant and animal foods[20–22]. Given our ecologic niche and cultural heritage, human omnivory is likely to continue into the future and at least some animal protein will be consumed as meat.

Livestock play important roles in the lives of humans as converters, recyclers and banks of nutrients. Livestock can effectively convert plant material that humans cannot easily digest, such as crop residues and forages, or food that humans would prefer not to ingest, such as insect-infested grain or a variety of food wastes, into highly desirable animal products. Animal husbandry has long been associated with crop production because of complementary nutrient cycles such as feeding crop residues to livestock which in turn provide manure for crop production[23]. Plant fertilizers in the form of manure and a means to utilize forages that are not well digested by humans are classic, multidimensional benefits of livestock husbandry. Manure is an important source of nutrients for smallholder's soils and crops[24]. Manure not only supplies nutrients, particularly plant-available forms of nitrogen and phosphorus at the time of application but also provides long-term benefits such as improved soil organic matter content and enhanced soil fertility reserves[24]. Forage crops are typically perennials and provide significant ecological benefits such as reducing soil erosion potential, enhancing soil structure, improving water infiltration rates and increasing soil organic matter as compared to annual grain crops[25,26]. Annual grains cultivated in rotation with leguminous forages such as alfalfa, clovers or vetch, produce larger grain harvests due to improved soil tilth and fertility[25,26].

The timing of nutrient availability is also a critical issue of food security. Seasonal fluctuations in grain availability throughout the year can be attenuated by keeping livestock[27]. Livestock can serve as nutrient banks for crops that would be lost due to spoilage or insect and animal predation during storage. Feeding these crops to livestock effectively preserves perishable calories and nutrients in a form that will be available at a later date. Finally, crops are seasonal and harvest does not necessarily coincide with need for cash income[28]. Alternatively, livestock can be sold throughout the year[28]. Animal agriculture can thus provide income to rural smallholders at critical times[7,19,28]. Keeping livestock can add greater diversity, stability and ultimately security to food supply and livelihood of smallholders[23,27,29]. It is clear that incorporating livestock into smallholder operations can be beneficial for the entire farm unit, especially if the livestock consumes forage crops or food wastes.

Livestock Species

Smallholders raise a diversity of livestock species and often raise multiple species simultaneously. Table 1 presents expected reproductive and growth characteristics of

selected livestock species under smallholder conditions. Each livestock species has attributes that are desirable. The purpose of this paper is not to identify the best livestock option for rural smallholders. Livestock species selection by producers is affected by a myriad of influences and conditions that are often specific to a given time and place. Thus identifying one, best species is not only impossible but also irresponsible. Examining the potential of species to fill certain niches is less problematic and that is the purpose of this paper. We first discuss several common species of livestock kept by smallholders under the context of improving food security through meat production. We highlight potential issues with each species that might limit their utility for meat production under smallholder conditions. We then examine the management and performance of guinea pig (*Cavia porcellus*) and discuss the potential this less-common species has for improving the food security of the rural smallholder.

Ruminant livestock—cattle (*Bos taurus*), goats (*Capra hircus*) and sheep (*Ovis aries*)—have a proven ability to convert fibrous non-starch polysaccharides into highly digestible animal proteins. These species of livestock typically supply draft power, milk and fiber to smallholders. Ruminants are valuable components of mixed crop and livestock farming systems, however, their lengthy reproductive cycle and growth period limit their utility for production of meat for home consumption and sale under smallholder conditions.

Swine (*Sus scrofa*) is a species that is quite common throughout the world and pork is the most widely consumed meat in both developing and developed nations[30]. Swine produce multiple litters of 8–12 young annually[31]. In the United States, growing swine fed typical corn–soybean meal diets will reach 130 kg live weight in less than 170 days, producing a 96 kg carcass[32]. Under smallholder conditions, management of swine's nutritional requirements and environment is likely to be less controlled. Performance of swine raised by smallholders may more realistically match benchmarks presented in Table 1 than North American production statistics. The existing body of research indicates that although swine can survive and grow on diets containing forages or other sources of non-starch polysaccharides, growth rates and performance of swine fed those diets are less than those exhibited by swine fed corn–soybean meal diets. For smallholders, production of swine for sale and ultimate consumption outside of the home might be hindered by potential human–swine competition for highly digestible starches and amino acids. Swine provide valuable recycling functions to a smallholder farm by consuming food and agricultural wastes, but those feedstuffs are generally not available to smallholders in sufficient quantities to support raising swine to regularly sell to others.

Chicken (*Gallus domesticus*) is another species of livestock commonly raised by rural smallholders. Growth and performance of chickens, a non-ruminant animal, is maximized when fed highly digestible starches and amino acids[33]. These sources of nutrients—grains and animal proteins—are also valuable foods for humans. Chickens can grow on diets containing non-starch polysaccharides, but at the cost of reduced net feed conversion[34]. Feeding exogenous non-starch polysaccharide enzymes to chickens may with time be an effective strategy to improve utilization of this feedstuff by chickens, but this approach has not yet been successful[35,36]. Exogenous enzymes to improve forage utilization by non-ruminants would most likely have to be purchased and so may conflict with the larger goal of reducing reliance on external inputs for food production. Many chickens raised by smallholders are allowed to scavenge and are only fed limited amounts of feed by the producer[37]. Scavenge-fed chickens are certainly an effective strategy to harvest available resources in many situations, particularly when laying hens are kept and eggs are consumed[37]. However, higher mortality rates, slower growth rates and reduced net feed conversion limit the utility of this strategy for producing consistent supplies of meat for consumption and sale[37].

Rabbit (*Orytolagus cuniculus*) is another species that may enhance the food security of rural smallholders. Rabbits are non-ruminant animals, but are able to utilize fermentation products of the cecum through coprophagy[38]. This adaptation enables rabbits to thrive on a variety of vegetation. Because of their legendary capacity for reproduction and their ability to thrive on forage, collectively rabbits can produce as much meat per unit of forage as larger ruminant animals, despite their considerably smaller size[38]. Rabbits are ideally sized for husbandry by women and children near the home. Unfortunately, their powerful hind legs allow rabbits to jump over barriers that would keep other small mammals confined. They also move relatively fast, making them difficult to recapture. In some areas, escaped rabbits have become a serious threat to crops and native vegetation[38]. In many situations, rabbits are well suited for production of meat under smallholder conditions. However, the potential for feral rabbits decimating natural and cultivated landscapes remains a barrier.

Cattle, goats, sheep, swine, chickens and rabbits all play important roles in the lives of rural smallholders. Under the context of meat production for both sale and home consumption, smaller species that reproduce rapidly and thrive on forage-rich diets are highly desirable. Of the species examined thus far, rabbits are particularly well suited for this role. Because increasing options for the smallholder is generally desirable, another less common species of livestock, guinea pig, will be the focus of the remaining discussion.

Guinea Pig

Guinea pigs (*C. porcellus*) are native to the Andes region of South America where they have been a valuable source of animal protein and income for centuries[39,40]. Guinea pigs are well suited to produce meat for home consumption and

for marketing in the context of rural smallholders. They are prolific animals—expressing non-seasonal estrus, have a gestation length that allows for multiple litters per year, and produce multiple young per birth event. Guinea pigs grow and reproduce on a flexible diet and are adaptable to a wide range of climates. They are also herd animals that respond favorably to husbandry and management.

Although most commonly raised in Latin America, guinea pig production has spread to parts of Asia and Africa[41,42]. The guinea pig is a herbivorous mammal with molar teeth, which continuously erupt and are well suited for grinding rough plant materials[43,44]. The guinea pig is classified as a non-ruminant animal with a functional cecum[44]. It has been demonstrated that adult guinea pigs can maintain body weight and young guinea pigs continue to grow normally on a cellulose-rich diet[43]. Basal diets were diluted with 50% cellulose resulting in a calculated caloric density decrease of 40%, yet the guinea pigs' growth curves were maintained without a corresponding increase in feed intake[43]. This demonstrates that guinea pigs may be able to derive more energy from cellulose than most non-ruminant livestock species. The cecum of the guinea pig has been shown to contain concentrations of short-chain fatty acids similar to those in the bovine gastrointestinal tract[45]. Absorption and metabolism of these short-chain fatty acids is likely the mechanism by which the guinea pig utilizes cellulose and other non-starch polysaccharides. Together these findings support accounts that guinea pigs can derive significant amounts of energy and essential nutrients from fibrous materials. The similarities between the cecum of the guinea pig and rabbit (*Oryctolagus cuniculus*) suggests that the rabbit's practice of recycling intestinal contents through coprophagy and thus harvesting B vitamins and indispensable amino acids synthesized by mircroorganisms in the hindgut may also occur in the guinea pig[44,46].

The biology of the guinea pig supports rapid increase in numbers of animals (Table 1). Guinea pigs used in research laboratories are typically 3 months or 400–600 g in body weight at the time of first mating[47]. Commercial meat growers in Ecuador first mate improved animals selected for meat production at 3.5 months of age or about 1000 g[48]. Following a 68-day-gestation period, female guinea pigs will give birth to a litter of 1–8 live young[41,48,49]. For guinea pigs raised for meat, litters of 3–4 young that are weaned at 15 days of age are typical[41,48,49]. Estrus is displayed immediately post-partum and if not impregnated the female will ovulate again in approximately 16 days[47,50]. This intense prolificacy can be obtained in commercial meat producing herds[41,48] although typical output per breeding female is closer to 4 litters of 3 animals annually[48–50]. Improved guinea pigs typically reach a market weight of 1000 g at 10–13 weeks of age with carcass weight ranging from 715–800 g[41,48,49]. Although there are multiple reports of these reproduction and growth rates being supported by a diet predominantly composed of grasses or alfalfa[40,41,48,49,51], precise determination of grain use by these animals under meat production conditions have not been fully quantified.

Table 2. Growth and performance characteristics of guinea pig (*C. porcellus*) raised for meat production.

Birth weight (kg)	0.10
Age at weaning (days)	14
Weight at weaning (kg)	0.20
Age at market (days)	90
Weight at market (kg)	1.10
Carcass weight (kg)	0.72
Feed consumed (kg of dry matter)	5.70
Diet (% concentrate)	10
Diet (% forage)	90
Carcass: Feed ($g\,g^{-1}$)	0.13
Carcass: Concentrate ($g\,g^{-1}$)	1.26

Suitablity for Smallholders

Table 2 presents detailed growth and performance characteristics of growing guinea pigs raised under smallholder conditions. Of greatest interest is the carcass yield per quantity of grain fed. Precise use of grain by guinea pigs under meat-production conditions has not been fully quantified. However, a commercial grower in Ecuador is currently feeding a diet of 90% forage and 10% grain on a dry matter basis and reports his animals achieve 1100 g of bodyweight at 10–13 weeks of age[48]. In this case, guinea pigs produce 1.26 g of carcass for every 1.0 g of grain consumed. Other reports suggest that for maximal meat production, up to 40% of the diet should be a concentrated feed such as grain[50]. By comparison, swine and chickens in the United States consume diets that are almost entirely grain-based and produce 0.3 and 0.5 g of carcass for every 1.0 g of grain consumed[52].

Carcass weight includes not only lean meat and fat, but also bone, which does not supply protein or energy to humans. Dissected laboratory guinea pigs have been shown to have a body composition of 40–62% lean tissue, 10–22% adipose tissue and 8–9% bone[53,54]. Dissection[6] of guinea pigs selected for meat production have not been performed making it difficult to compare the relative amounts of muscle, fat and bone produced by guinea pigs with other more extensively studied species of livestock. Size is also a consideration in the actual harvesting of the animal. A guinea pig can be easily harvested by a single young adult in as few as 10 min, processing a much larger goat or swine requires more labor and time.

Diets consisting of primarily forage support high fecundity and rapid growth by guinea pigs[41,48,51]. Livestock enterprises using feedstuffs that humans cannot or do not use are more appropriate for smallholders seeking to increase their income through the sale of meat. Under smallholder conditions it is common to feed guinea pigs kitchen wastes and other foods that are judged unfit or inappropriate for human consumption. Because guinea pigs

are relatively small animals that grow very well on little grain, they make excellent kitchen waste recyclers for smallholders.

Traditionally, guinea pigs were kept within the home of rural smallholders[39,40,48]. Typically, the guinea pigs would have free-range of the kitchen area or be confined to a corner near the stove or fire. Under commercial meat production, 10–15 growing guinea pigs are typically kept in 1×1 m pens[48]. Guinea pig pens are simple square structures with 0.6-m high walls surrounding a solid floor. Pens are located within a larger building that often also serves as a storage shed for food, feedstuffs and agricultural tools. A bedding pack of absorbent material, most commonly small grain straw or rice hulls, approximately 7 cm thick is placed directly on the ground and the guinea pigs maintain distinct areas for sleeping, eating and defecating[48]. Water is provided via fresh forage and supplemental grains are fed using a simple trough.

Zoonoses—diseases transmitted from other animals to humans—are a risk to human health associated with keeping livestock[29]. The magnitude of this risk for each species and how to address zoonoses most effectively is not fully understood[29]. Given that guinea pigs have been raised by humans for centuries it is likely that in many cases mutual resistance or tolerance has developed, although this does not preclude the possibility of novel and epidemic zoonoses arising in the future. When raised in a clean environment under normal feeding conditions, guinea pigs are healthy and productive animals[41,50,51]. As with other species, when stressed by unsanitary conditions, inadequate nutrition, drafts and pathogens, guinea pig performance is depressed. Guinea pigs are susceptible to pneumonia and salmonella as well as internal and external parasites[41,50,51]. Guinea pigs can also be carriers of Chagas' disease[41] and coccidiosis is sometimes common[41,51]. Similar to other species of livestock, avoiding contact with disease vectors, good hygiene and adequate nutrition results in healthy guinea pigs.

Development through livestock can occur in several ways[6]. One model locates production within smallholder farms where families raise animals for both home consumption and sale outside of the home. Benefits and costs of production are immediately enjoyed or felt by the smallholder owner operator, thus encouraging the evolution of effective strategies to address a given situation. The economic and social advantages of a community composed of self-determining yet interconnected citizen-producers has long been hailed as cornerstones of responsible civilization[55] and democracy[10]. Another very different approach involves industrialized production directed by an individual or group able to secure investment and operating capital. Smallholder and rural poor can be employed as wage labor by these firms, generating needed income for the household. Increased income can lead to greater food security through increased ability to purchase available food[6]. However, in situations of market shortage and price increases those whose access to food is limited to buying it are generally less able to obtain adequate nutrition than producers of food.

Livestock have long been used as 'living savings accounts' providing protection against risks of economic, social and environmental instabilities[28,56,57]. Livestock can be sold and transformed into cash as needed, providing liquidity and consumption smoothing to seasonal income from crop production[28]. Livestock can be sold in times of crisis, thereby serving as insurance to a family with limited assests[28,58]. The size and growth rate of guinea pigs make them excellent means of generating both food for the table and cash income while continuing to sustain the ability to generate income into the future. For example, consider a producer who has resources to produce one 120-kg swine or one hundred, 1100-g guinea pigs per year. The guinea pigs could be managed in such a way that small but steady income and nutrition streams flow from the guinea pig herd. Alternatively a single swine produces one large pulse of nutrition or income. The larger number of guinea pigs also provides security from disease and other risks—if the one swine owned by the producer contracts a disease and fails to grow, the entire income/nutrition benefit is imperiled. Alternatively if half the guinea pigs fail to grow they represent only a portion of the herd. With more individuals, the guinea pig herd itself is more likely to survive unpredictable impediments to production and recover to full capacity more quickly.

Gender often plays an important role in rural poverty and food insecurity[59–62]. When women control the production and marketing of crops and livestock, the results are more likely to improve the family's nutritional status or address other critical family needs such as school fees or medical expenses[60–62]. When higher percentages of total family income are controlled by mothers, children's nutritional status improves[62]. Blumberg[60] reviewed multiple studies conducted in several developing countries and found that income managed by women was more likely to be devoted to sustaining the family unit than income managed by men. While in some cases, increasing the income level of men resulted in improving nutritional status and overall well being of the family, in others it did not[60]. Women and children are typically responsible for guinea pig production under smallholder conditions[40]. A herd of guinea pigs large enough to produce both meat for the table and cash income can easily be kept near the family dwelling and managed entirely by family labor[40,41,49].

Improving the livelihood of the rural poor through increased meat animal production should be coupled with enhanced market access and information[63]. Guinea pig cooperatives as described by Morales[40] can enhance marketing power of smallholders by pooling production of multiple producers together. The expanding mobile phone network within developing countries[64] also enhances the marketing position of smallholders by increasing access to critical market information across large geographical distances[65]. The ability to communicate verbally with calls to prospective buyers before undertaking day-long or more

journeys to market gives smallholders the opportunity to more effectively use their time and direct their product.

Conclusions

Production of meat animals can improve family nutrition and income of smallholder farms. The guinea pig is a valuable species that can improve the livelihood of smallholders. As a species that performs well on diets consisting primarily of forages, the guinea pig does not compete with humans for sources of nutrition. The management and care of guinea pigs is often performed by women and children, which may offer additional development benefits. Awareness and acceptance of the guinea pig as a source of nutrition and income is less than ubiquitous. The biological, ecological and economic advantages of guinea pigs deserve further attention by those working to alleviate global poverty and food insecurity.

Acknowledgements. This paper was supported by the Hatch Act, State of Iowa funds, Iowa State University College of Agriculture and Life Sciences Agriculture Study Abroad Program, Department of Animal Science, Department of Agronomy, Graduate Program in Sustainable Agriculture and Practical Farmers of Iowa.

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Book Review

Agriculture in Developing Countries—Technology Issues. By Keljiro Otsuka and Kaliappa Kalirajan. 2008. Sage Publications Pvt. Ltd, London, UK. 172 p. Hardcover 29.99 GBP ($43.28), ISBN 9780761936626.

Combining indigenous knowledge of farmers with modern agricultural technologies to create a participatory development is the central idea of this book, which in fact is a compilation of papers presented at the 26th Conference of the International Association of Agricultural Economists, held in Australia from 12 to 18 August 2006. The editors tried and succeeded in selecting interesting papers which, at least most of them, show convincing examples of how to combine the contrasting elements of traditional farmer knowledge with modern, scientifically based technological approaches in one strategy. The book is divided into eight chapters including an introductory chapter written by the editors themselves and hence describes seven specific research projects carried out independently in six Asian countries.

The introductory chapter discusses the known phenomenon of gaps between researcher and farmer yields, but also the farmers' own yield gaps, i.e. the non-realization of site-specific yield potentials due to management reasons. According to the editors, farmers' indigenous knowledge and modern scientific knowledge are not substitutes for each other, but are complementary towards achieving the objective of improving the welfare conditions of the farming community. The introductory chapter ends with a summary of the following papers, however neither in the correct order nor complete (no summary of chapter 3).

Chapter 2 entitled 'Economic assessment of an indigenous technology in Bangladesh' describes a case study, which demonstrated the importance of developing scientific research in unfavorable areas while taking into account the local experience of the farmers as well. The authors have assessed the economic efficiency of the 'double transplantation' system for rice applied by local farmers and compared it to a single transplantation system commonly practised in Bangladesh. It was possible to identify environmental conditions under which one of the systems turned out to be more favorable.

In chapter 3 'Research investment on technology development in Peninsular India', the authors try to evaluate the economic value of research in Karnataka, a predominantly agricultural state in India. Based on their calculations they conclude that agricultural research considerably affected the release of improved varieties and other technologies that, for most species, increased crop productivity. Likewise, the rate of return of research investments was dependent on the crop species.

In chapter 4 'Impact of forage options for beef production', the authors examine the influence of the crop–cattle technology on improving economic conditions in China. By analyzing data from smallholder households of 11 villages in two Chinese provinces it could be shown that the strategy of establishing mixed farming systems, including both ruminant husbandry and fodder crop production, can be an economically profitable option for smallholder households in China.

Chapter 5 entitled 'Optimal land use with carbon payments and fertilizer subsidies in Indonesia' is a well written concise economic report dealing with alternative land use options targeted on increasing carbon sequestration by including small-scale forestry and agro-forestry with traditional maize growing in Sumatra. The authors developed a meta-model of an agro-forestry system and incorporated it into a dynamic programming algorithm to determine profit-maximizing management strategies in the presence of carbon payments and fertilizer subsidies. Based on various sophisticated models and calculations, the authors concluded that the main determinants for farmers are the initial carbon content of the soil and fertilizer prices, as well as the presence/absence of carbon payments.

The following chapter entitled 'Deterioration of tank irrigation systems and poverty in India' analyzes in detail the impact of changing irrigation from traditional tank to modern pump-based systems in Tamil Nadu, India. The authors further discuss the economical and social implications of the current decline of collective management of irrigation systems and the subsequent emergence of private wells with limited access for users. Based on extensive data evaluation of rice yields and profit on rice, the authors conclude that 'the dissemination of private wells results in double tragedies in that the non-well users suffer increased poverty due to the decline in collective management of tank irrigation systems; even the well users suffer reduced profit on rice due to the overexploitation of groundwater'. The study is completed by a discussion of policy implications, giving some clear suggestions on how to overcome the water scarcity problem by revitalizing collective management of irrigation systems.

Chapter 7, named 'Agricultural technology and children's occupational choice in the Philippines', is a long-term analysis of the impact of increased income generation by using modern agricultural technologies, mainly modern rice varieties and irrigation, on schooling investments. The

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authors used a rare panel dataset collected in 1985, 1989, 2001 and 2004 in the rural Philippines. In particular, the authors explored the changing importance of agricultural technology, land and human capital in determining household income and schooling investment decisions over time. Based on a large set of empirical data and a concise evaluation, the authors conclude that 'overall the regression results give evidence that modern agricultural technology significantly affects children's progress in school' and that 'the fact that school progress is significantly affected by household income indicates that schooling remains a superior good in the rural Philippines'.

The last chapter of this book is dedicated to 'A panel data model for the assessment of farmer field schools in Thailand'. The authors developed and applied a sophisticated model that includes a wide range of data on farmers' knowledge on rice and pest management as well as on rice yields and pesticide use. They analyzed whether and to what degree the participation in farmer field schools (FFS) can contribute to a reduction of pesticide use via teaching and knowledge transfer to farmers. The results of the study showed that FFS farmers significantly succeeded in reducing their pesticide use (−41.7%), while maintaining the overall crop productivity. The analysis has been carried out by testing for change in performance in the growth of environmental impact parameters, namely the quantity of pesticides used and the environmental impact quotient (EQI). Again the farmers participating in FFS showed a better performance. The authors conclude that the participation in FFS 'can help farmers to sustainably change pesticide-use practices'.

All in all, this book is an interesting and well-written source for people interested in the rural development of developing countries in Asia, even if it is mainly based on economic models. No need to remind the reader that the value of economic models in general is mainly a function of the quality of the data that have been used. In any case, all contributions are concise and abundantly supplied with empirical data clearly shown in various tables and graphs. Most of the papers are also easy for non-economists to understand, while some others seem to be exclusively targeted on agricultural economists, leading to the question, 'For which audience has the book been written?' Also, the selection criteria and the presentation order for the papers are not conclusive. An adequate use of the results, especially by policy makers and advisors in developing Asian countries, would certainly need another way of presentation and the integration of further factors, such as policy. Whenever considering a practical application of the research results in the various countries, the further integration of other stakeholders, such as crop production experts, would also be useful.

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doi:10.1017/S1742170509002488
First published online 17 March 2009

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Renewable Agriculture and Food Systems

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